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Entraînement de la mémoire chez les personnes âgées ayant une plainte mnésique : contribution de la réalité virtuelle au transfert et rôle de l’attention

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Résumé

Les stades prodromiques de la maladie d'Alzheimer offrent une fenêtre d'intervention critique pour optimiser la cognition grâce à l'entraînement cognitif, et ainsi potentiellement limiter les atteintes cognitives en installation. Or, les effets de transfert des interventions cognitives demeurent incertains. Les travaux de cette thèse portent sur l'amélioration de la validité écologique d'un entraînement mnésique afin d'en favoriser les effets de transfert, soit via l'utilisation de la réalité virtuelle (RV) immersive, soit par l'ajout d'une tâche d'inhibition de bruit verbal ambiant.

La première étude (Chapitre II) avait pour objectif de concevoir et d'évaluer la faisabilité et la validité de La boutique virtuelle. D'abord, une tâche de RV a été conçue pour permettre d'évaluer la mémoire dans un contexte près du quotidien. Vingt jeunes et 19 personnes âgées ont réalisé la tâche avec une variabilité suffisante de résultats, appuyant sa faisabilité. La performance des jeunes était supérieure à celle des personnes âgées. Puis, chez 35 individus âgés avec un déclin cognitif subjectif, le score obtenu en RV s'est vu corrélé avec ceux obtenus à une mesure de mémoire épisodique et à une mesure de mémoire quotidienne auto-rapportée. Ces résultats supportent la validité de construit et la validité écologique de La boutique virtuelle.

La deuxième étude (Chapitre III) avait pour but d'examiner les effets de transfert de contexte d'un entraînement mnésique, en utilisant la RV comme outil de promotion et de mesure du transfert de contexte, et en explorant le lien dose-réponse. Les effets de transfert en RV étaient comparés à ceux obtenus sur un questionnaire auto-rapporté. Quarante personnes avec plainte mnésique ont complété six séances d'entraînement à la méthode des lieux. La moitié des participants pratiquait aussi la méthode dans La boutique virtuelle, tandis que les autres y réalisaient un exercice de détection. Suite à l'entraînement, la performance des deux groupes s'est améliorée aux tâches en RV, mais pas sur le questionnaire. Ces effets suggèrent un transfert des bénéfices de l'entraînement dans des tâches près du quotidien, et que la RV est sensible à ces effets de transfert. L'ajout d'exercices en RV ou l'augmentation de la dose d'entraînement ne semblent pas augmenter les effets de transfert.

La troisième étude (Chapitre IV) visait à évaluer si un entraînement mnésique pouvait s'avérer plus efficace lorsqu'il était additionné d'exercices en contexte d'inhibition auditive. Quarante personnes âgées avec plainte mnésique ont complété six séances d'entraînement à la méthode des lieux. Les participants apprenaient la méthode des lieux pendant les séances 1 à 3. Lors des séances 4 à 6, la moitié des participants réalisait les exercices en contexte de bruit verbal, dont le niveau de distractibilité variait graduellement. Suite à l'entraînement, tous ont amélioré leur rappel de mots en silence et dans le bruit, jusqu'à éliminer l'effet délétère de celui-ci. Les résultats suggèrent qu'un entraînement à la méthode des lieux est suffisant pour améliorer la performance mnésique en contexte de bruit verbal. Réaliser l'entraînement dans le bruit n'apparaît pas mener à des bénéfices supérieurs.

Cette thèse a permis de soutenir la faisabilité et la validité de l'utilisation de la RV en contexte d'évaluation mnésique chez les personnes jeunes et âgées et de mettre de l'avant l'obtention d'effets de transfert suite à un entraînement mnésique. Elle met toutefois en exergue les défis inhérents à l'amélioration des protocoles d'intervention.

Mots-clés : entraînement cognitif, mémoire, attention, inhibition, bruit, réalité virtuelle, méthode des lieux, transfert, vieillissement, plainte mnésique.

Abstract

The prodromal stages of Alzheimer's disease offer a critical window of opportunity for interventions aiming to optimize cognition through cognitive training, thus potentially limiting cognitive impairment. However, the transfer effects of cognitive interventions remain uncertain. The work of this thesis focuses on the improvement of the ecological validity of memory training in order to foster its transfer effects, either through the use of immersive virtual reality (VR), or by adding an inhibition task involving ambient verbal noise.

The first study (Chapter II) aimed to design and evaluate the feasibility and validity of the Virtual Shop (i.e., *La boutique virtuelle*). First, a VR task was designed to evaluate memory in a context similar to everyday life. Twenty young adults and 19 older adults completed the task with sufficient variability in the results, thus supporting its feasibility. The performance of the young adults was higher than that of the older adults. Second, in 35 older individuals with subjective cognitive decline, the scores obtained in VR were correlated with those obtained on a measure of episodic memory and on a self-reported measure of daily memory. These results support the construct validity and ecological validity of the Virtual Shop.

The second study (Chapter III) aimed to examine the transfer effects of memory training, using VR as a tool for promoting and measuring context transfer, and exploring the relationship between dose and response. The transfer effects in VR were compared to those obtained on a self-reported questionnaire. Forty individuals with memory complaints completed six training sessions on the method of loci. Half of the participants also practiced the method in the Virtual Shop, while the others performed an exercise of visual detection. Following training, the performance of both groups improved in the VR tasks, but not on the questionnaire. These effects suggest a transfer of the benefits of training to everyday tasks, and that VR is sensitive to these transfer effects. Adding VR exercises or increasing the training dose does not appear to increase the transfer effects.

The third study (Chapter IV) aimed to assess whether memory training could be more effective when combined with exercises in the context of auditory inhibition. Forty older adults with memory complaints completed six training sessions on the method of loci. Participants learned the method of loci during sessions 1-3. In sessions 4-6, half of the participants completed exercises in the presence of verbal noise, of which the level of distractibility gradually varied. Following training, everyone showed improvement in word recall, in both the silent and noisy conditions, until eliminating the deleterious effect of noise. The results suggest that training in the method of loci is sufficient to improve memory performance in the context of verbal noise. Training in noisy environments does not seem to lead to more benefits.

This thesis helped support the feasibility and validity of the use of VR in the context of memory evaluation in young and older adults and to put forth the transfer effects following memory training. However, it also highlights the challenges inherent in improving intervention protocols.

Keywords : cognitive training, memory, attention, inhibition, noise, virtual reality, method of loci, transfer, aging, memory complaint.

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Liste des sigles

En français

ANOVA : Analyse de variance

DCS : Déficit cognitif subjectif

MA : Maladie d'Alzheimer

RV : Réalité virtuelle

TCL : Trouble cognitif léger

En anglais

ACTIVE: Advanced Cognitive Training for Independent and Vital Elderly

ADCS: Alzheimer's Disease Cooperative Study

ADL-PI: Activities of Daily Living-Prevention Instrument

ADNI: Alzheimer's Disease Neuroimaging Initiative study

BNT: Boston naming test

CVLT: California Verbal Learning Test

GDS: Geriatric depression scale

HMD: Head-mounted display

IVR: Immersive virtual reality

LM: Logical memory

MCI: Mild cognitive impairment

MMQ: Multifactorial Memory Questionnaire

MoCA: Montreal Cognitive Assessment

RL/RI-16: Rappel libre/rappel indicé à 16 items

SCD: Subjective cognitive decline

SPSS: Statistical Package for Social Sciences

WMS: The Wechsler Memory Scale

Liste des abréviations

Cf. : Confer (reportez-vous à)

E.g. : Exempli gratia (par exemple)

Et al. : Et alii (et autres)

Etc. : Et cætera

I.e. : Id est (c'est-à-dire)

P.ex. : par exemple

S : seconds

Vs : versus

Vs. : versus

À Simon, qui veille sur nous parmi les nuages.

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Chapitre I

Introduction générale

Contexte

Le vieillissement démographique est un phénomène qui marquera le visage des sociétés occidentales des prochaines années. Alors que les personnes âgées de 65 ans et plus représentaient 16,9 % de la population canadienne en 2016, Statistique Canada (2017) estime que cette proportion aura atteint plus de 25 % en 2061. Le vieillissement s'accompagne de plusieurs défis, dont le déclin normal de la cognition (Park et al., 2002) et l'augmentation des cas de maladie d'Alzheimer (MA). En effet, dès 65 ans le risque de développer la MA ou une maladie apparentée double tous les cinq ans (OMS, 2012). Depuis quelques années, il y a un intérêt grandissant pour le rôle que pourrait jouer l'intervention cognitive dans l'optimisation ou la prévention du déclin cognitif dans le vieillissement. Parmi les interventions cognitives, l'entraînement de la mémoire a démontré son efficacité pour améliorer la cognition des aînés sains (voir Verhaeghen, Marcoen, & Goossens, 1992, pour une méta-analyse) ou dans les phases prodromiques de la MA (voir Gates, Sachdev, Singh, & Valenzuela, 2011, pour une revue). Toutefois, il n'est pas clair si ces acquis mènent à des effets de transfert dans la vie de tous les jours. D'abord, il existe peu d'outils de mesure pertinents à cet effet, et peu d'études se sont penchées sur le développement d'approches ou de stratégies qui favorisent directement le transfert. Il est pourtant essentiel de s'intéresser à cette notion de transfert, si l'on veut démontrer que les interventions permettent réellement de réduire l'impact des difficultés cognitives dans la vie de tous les jours et d'optimiser la qualité de vie des individus. Dans le même ordre d'idées, les entraînements mnésiques actuels ne ciblent pas précisément l'amélioration de la mémorisation dans des contextes complexes et/ou exigeants. Or, dans la vie de tous les jours, la mémorisation doit souvent se faire en présence de bruit ambiant, ce qui peut incommoder les aînés (Langlois & Belleville, 2014). L'inhibition de distracteurs est d'ailleurs un trouble documenté dans le vieillissement normal et dans les phases prodromiques de la MA (Radvansky, Zacks, & Hasher, 2005 ; Drzezga et al., 2005 ; Johns et al., 2012). Un entraînement ciblant à la fois la mémoire et l'inhibition de distracteurs auditifs serait donc tout indiqué chez les aînés.

En tant que stade précoce de la MA, le trouble cognitif léger (TCL) est considéré par plusieurs chercheurs comme une période cruciale pour offrir des interventions cognitives

(Albert et al., 2011). Toutefois, il y a maintenant consensus à l'effet que la maladie débute de nombreuses années avant la pose du diagnostic, et donc bien avant l'apparition des symptômes du TCL (Sperling et al., 2011). Récemment, il a été proposé que le déclin cognitif subjectif (DCS) puisse correspondre chez certains individus à un stade encore plus précoce de la MA (Jessen et al., 2014 ; Dubois et al., 2016). Les personnes avec un DCS ont une plainte subjective mais ne montrent pas d'atteinte cognitive détectable par les outils cliniques actuels. Ainsi, cette condition pourrait offrir une fenêtre d'intervention plus appropriée que le TCL.

L'objectif de cette thèse est de répondre à ces lacunes 1) en enrichissant un entraînement de la mémoire afin que ses exercices soient plus fidèles aux défis de la mémorisation dans la vie réelle, tout en testant l'efficacité de ces enrichissements chez des personnes avec DCS et 2) en mettant au point et en utilisant des mesures appropriées pour évaluer le transfert dans des situations près du quotidien chez les individus avec DCS. La première partie de l'introduction de la thèse présentera la MA, en portant une attention particulière aux stades prodromiques de la maladie. Les déficits cognitifs présents lors de ces stades y seront également documentés. La seconde partie portera sur l'intervention cognitive chez la personne âgée avec ou sans troubles cognitifs. La troisième partie traitera de la notion de transfert dans la vie quotidienne. La quatrième partie abordera le potentiel qu'offre la réalité virtuelle (RV) pour la promotion et la mesure du transfert. Enfin, les objectifs généraux de la thèse ainsi que les objectifs et hypothèses reliés à chaque article seront présentés.

1.1. La maladie d'Alzheimer et ses stades précoces

La MA est une maladie neurodégénérative qui se manifeste par la présence de déficits cognitifs sévères menant à une altération significative du fonctionnement quotidien (McKhann et al., 1984 ; McKhann et al., 2011). Actuellement, 47,5 millions de personnes dans le monde sont atteintes de MA ou d'une maladie apparentée (OMS, 2016). Étant donné la perte d'autonomie fonctionnelle graduelle caractérisant la MA, le patient atteignant les stades plus sévères de la maladie aura besoin d'assistance et de soins, et les répercussions sur sa vie quotidienne seront donc considérables. Le fardeau de la prise en charge est par conséquent énorme pour le système de santé. Seulement en 2017, les coûts associés à la MA et aux maladies apparentées étaient estimés à 259 millions de dollars américains aux États-Unis (Alzheimer's Association, 2017).

1.1.1. La maladie d'Alzheimer

Du vivant du malade, le diagnostic de la MA repose sur l'observation d'un ensemble de symptômes cognitifs qui ne peuvent être expliqués par d'autres causes biologiques ou psychologiques. D'abord, les critères du trouble neurocognitif majeur (ou démence) doivent être remplis : 1) évidence d'un déclin cognitif significatif par rapport au niveau de performance antérieur, dans au moins un domaine cognitif ; 2) interférence avec les activités de la vie quotidienne. Ensuite, pour que le trouble neurocognitif soit attribuable à la MA, les critères suivants doivent s'ajouter au tableau clinique : 3) début insidieux et progression graduelle des difficultés ; 4) atteinte précoce et proéminente de la mémoire épisodique. À noter qu'un tableau possible mais moins fréquent met de l'avant un déficit initial et proéminent du langage, des fonctions exécutives ou des habiletés visuospatiales. La présente thèse se concentrera toutefois sur le profil le plus typique, atteignant d'abord la mémoire épisodique. L'atteinte de ces critères appuie un diagnostic de MA *probable*, car le diagnostic certain ne peut être posé que sur la base d'un examen post-mortem des tissus cérébraux. La MA présente effectivement des signes histo-pathologiques caractéristiques. Ainsi, le diagnostic final requiert non seulement qu'un patient ait présenté tous les signes cliniques de la MA de son vivant, mais aussi que son cerveau montre des dégénérescences neurofibrillaires intracellulaires et des dépôts extracellulaires de protéine bêta-amyloïde (McKhann et al., 2011 ; American Psychiatric Association, 2013).

Il est maintenant reconnu que la MA implique une longue période prodromique s'échelonnant sur plusieurs années, voire des décennies, avant que le diagnostic ne soit posé (Amieva et al., 2008 ; Sperling et al., 2011). Sperling et ses collaborateurs proposent un modèle illustrant le « continuum pathologique et clinique de la MA », débutant par une *phase préclinique*, suivie d'une phase de *trouble cognitif léger*, puis se terminant par la *phase démentielle*, alors que le diagnostic probable de MA est posé. La présente thèse s'intéressera justement à ces stades précliniques, et tout particulièrement à celui du DCS (Jessen et al., 2014), celui-ci offrant actuellement la fenêtre d'intervention la plus précoce possible au sein du décours temporel de la MA, en amont de celle du trouble cognitif léger.

1.1.2. Le trouble cognitif léger

Le trouble cognitif léger (TCL ; *Mild cognitive impairment, MCI*), aussi dénommé *trouble neurocognitif mineur* selon l'American Psychiatric Association (American Psychiatric Association, 2013), représente un profil cognitif intermédiaire entre le vieillissement normal et la démence. Le plus souvent, il serait annonciateur d'une MA en phase précoce (e.g., Petersen et al., 2001 ; Petersen, 2002 ; Bruscoli & Lovestone, 2004 ; Gauthier et al., 2006 ; Sperling et al., 2011 ; Albert et al., 2011 ; Jessen et al., 2014). Selon les plus récents critères du National Institute of Heath, les personnes répondant aux critères du *TCL dû à la MA* présentent : 1) une inquiétude par rapport à leur cognition, formulée par la personne elle-même, un proche et/ou un clinicien ; 2) une atteinte d'une ou de plusieurs fonctions cognitives, se caractérisant par une performance plus faible qu'attendue pour l'âge et le niveau d'éducation ; bien que plusieurs fonctions cognitives puissent être touchées (e.g., fonctionnement exécutif, attention, langage et/ou habiletés visuospatiales), la mémoire épisodique est la fonction la plus souvent atteinte chez les individus qui développeront une MA par la suite ; 3) une autonomie préservée dans la vie quotidienne ; 4) une absence de démence (Albert et al., 2011).

Des chercheurs soutiennent que cette période pré-démentielle qu'est le TCL serait idéale pour favoriser la plasticité cognitive, soit la capacité de modifier ou d'améliorer ses capacités cognitives via différentes interventions (Tomycz & Friedlander, 2011). En effet, l'intervention cognitive pourrait aider les personnes avec TCL à compenser leurs difficultés cognitives au quotidien, et possiblement retarder l'apparition des difficultés fonctionnelles liées au trouble neurocognitif. Cependant, les déficits cognitifs présents dans le TCL suggèrent que la MA est déjà bien installée dans le cerveau de l'individu, du moins chez ceux qui progresseront vers le diagnostic de MA. Comme des recherches récentes proposent une condition symptomatologique liée à un stade pré-démentiel encore plus précoce (le déclin cognitif subjectif), l'intervention pourrait maintenant être prodiguée encore plus tôt. En effet, dans bon nombres de pathologies, l'intervention la plus précoce possible est habituellement indiquée (Reisberg & Gauthier, 2008). Selon Reisberg et Gauthier, le stade démentiel de la

MA serait probablement déjà très avancé pour l'intervention, tandis que le TCL ferait office de stade intermédiaire. Pour ces auteurs, le DCS représenterait un stade précoce – chez certains individus – où l'intervention est non seulement indiquée, mais nécessaire.

1.1.3. Le déclin cognitif subjectif

Les critères du déclin cognitif subjectif (DCS ; *Subjective cognitive decline*, *SCD*) sont les suivants : 1) une impression persistante et subjective de présenter un déclin cognitif par rapport à son propre niveau antérieur jugé normal, sans que ce déclin soit lié à un événement particulier ; 2) une performance cognitive non déficitaire en fonction de l'âge et du niveau d'éducation, telle que mesurée par des tests cognitifs standardisés ; 3) une absence de TCL ou de démence ; 4) l'absence d'un trouble psychiatrique, d'un trouble neurologique, d'une affection médicale ou d'un abus de substance pouvant expliquer les symptômes (Jessen et al., 2014 ; Sperling et al., 2011).

La plainte mnésique, touchant de 25 % et 56 % de la population âgée (Jonker, Geerlings, & Schmand, 2000), a longtemps été considérée comme bénigne. Bien que certaines études transversales suggéraient un lien entre la plainte de mémoire et une plus faible cognition (Christensen et al., 1991 ; Gagnon et al., 1994 ; Bassett & Folstein, 1993 ; Jonker, Launer, Hooijer, & Lindeboom, 1996), plusieurs études la reliaient davantage aux symptômes dépressifs/anxieux ou aux traits de personnalité (O'Connor, Pollitt, Roth, Brook, & Reiss, 1990 ; Barker, Prior, & Jones, 1995 ; Derouesné, Lacomblez, Thibault, & Leponcin, 1999 ; Minett, Dean, Firbank, English, & O'brien, 2005 ; Minett, Da Silva, Ortiz, & Bertolucci, 2008 ; Weaver Cargin, Collie, Masters, & Maruff, 2008). Par ailleurs, l'étude du lien entre la plainte et la cognition d'un point de vue transversal, soit à un même moment dans le temps, présente des limites. Premièrement, la notion de *déclin* n'est pas abordée directement, celle-ci impliquant une diminution de la cognition dans le temps. Également, plusieurs individus avec DCS pourraient présenter une perte cognitive encore non détectable par des tests cognitifs classiques (Reisberg & Gauthier, 2008). Récemment, une méta-analyse a toutefois mis de l'avant un lien significatif entre la performance de mémoire subjective et objective chez les personnes âgées (Crumley, Stetler, & Horhota, 2014). Bien que très modeste (r = 0,06) ce lien suggère aujourd'hui que la plainte reflète bel et bien le fonctionnement cognitif de l'individu.

Au-delà des études transversales, nombre d'éléments supportent maintenant que le DCS traduise une phase préclinique de la MA, encore plus précoce que le TCL (Jessen et al., 2014). D'abord, des études longitudinales montrent un lien entre la plainte de mémoire sans déficit cognitif et l'augmentation des risques de subir un déclin cognitif (Dik et al., 2001 ; Jorm, Christensen, Korten, Jacomb, & Henderson, 2001 ; Dufouil, Fuhrer, & Alpérovitch, 2005 ; Hohman, Beason-Held, Lamar, & Resnick, 2011), ou de développer un TCL ou une démence dans les années qui suivent (Geerlings, Jonker, Bouter, Adèr, & Schmand, 1999 ; St John & Montgomery, 2002 ; Wang et al., 2004 ; Glodzik-Sobanska et al., 2007 ; van Oijen, de Jong, Hofman, Koudstaal, & Breteler, 2007 ; Reisberg, Shulman, Torossian, Leng, & Zhu, 2010 ; Jessen et al., 2010 ; Chen et al., 2017). Selon une méta-analyse (Mitchell et al., 2014), le risque de développer une démence est doublé chez les personnes avec DCS, comparativement à celles sans DCS. Sur un suivi de 4 ans, il apparaît même que 24,4 % des personnes avec DCS développeront un TCL ou une démence, alors que ce ne sera le cas que pour 4,6 % des individus sans DCS.

Ensuite, des études transversales ont mis en évidence que les individus répondant aux critères du DCS montraient une prévalence accrue de biomarqueurs caractéristiques de la MA, comparativement à la population générale (Tepest et al., 2008 ; Visser et al., 2009 ; Amariglio et al., 2012). Enfin, il semble que les individus qui présentent à la fois des biomarqueurs de la MA et un DCS ont des risques encore plus importants de futur déclin cognitif et de progression vers le TCL et la MA (Prichep et al., 2006 ; van Harten et al., 2013 ; Peter et al., 2014).

Il importe d'être conscient que les individus présentant un DCS représentent une population hétérogène. De nombreuses causes peuvent être sous-jacentes et ce n'est pas tous les individus avec DCS qui progresseront vers la démence (Jessen et al., 2014). Même si les individus DCS ne peuvent pas être considérés dans une phase préclinique de la MA (Dubois et al., 2016), il demeure qu'une certaine proportion d'entre eux s'y retrouvent.

L'intérêt de l'intervention cognitive chez des individus âgés avec DCS est grand. 1) Étant donné que les personnes avec DCS ont un risque plus important de développer une démence que la population générale, elles représentent les personnes âgées les plus susceptibles de bénéficier d'une intervention qui pourrait éventuellement prévenir ou retarder le déclin cognitif via l'optimisation de leur fonctionnement cognitif actuel. 2) Le DCS pourrait représenter un stade préclinique de la démence encore plus précoce que le TCL. L'intervention dans le DCS offre donc la possibilité de cibler les individus lors des premiers symptômes de la maladie. 3) Comme les personnes avec DCS n'ont pas d'atteinte cognitive objective, elles disposent des ressources cognitives et métacognitives optimales pour apprendre et appliquer des stratégies dans leur quotidien. 4) Comme elles ont une plainte, elles sont conscientes de la présence d'une atteinte et donc fortement motivées. 5) Étant donné que le vieillissement normal s'accompagne d'un déclin cognitif (ne devenant toutefois jamais assez sévère pour altérer l'autonomie fonctionnelle), les individus avec DCS ne se trouvant pas dans un stade préclinique de la démence bénéficieraient également des interventions.

1.1.4. Les déficits cognitifs

Avant la mise en place d'une intervention cognitive au sein des stades précoces de la MA, il importe de connaître les déficits cognitifs présents lors de cette période. Ainsi, il sera possible de déterminer les meilleures cibles d'interventions. Dans cette partie, nous allons nous attarder au TCL, étant donné que par définition, il est attendu à ce que la cognition soit largement préservée dans le DCS. L'intérêt porté aux fonctions cognitives atteintes dans le TCL découle aussi du fait qu'elles seront éventuellement les premières touchées chez les individus présentant un DCS.

1.1.4.1. La mémoire épisodique

En ce qui a trait au TCL, la principale atteinte concerne la mémoire épisodique (Albert et al., 2011; Belleville, Sylvain-Roy, de Boysson, & Menard, 2008). Ce type de mémoire permet l'encodage, la consolidation et la récupération des informations personnellement vécues situées dans leur contexte spatio-temporel (Tulving, 1972). D'abord, des déficits sont observés dans le rappel de listes de mots, de courts textes, et de matériel non verbal, qu'il soit question de rappel immédiat ou différé, en condition libre (Dudas, Clague, Thompson, Graham, & Hodges, 2005 ; Hudon et al., 2006 ; Perri et al., 2005 ; Petersen et al., 1999) ou indicée (Adam et al., 2007 ; Hudon et al., 2006 ; Ivanoiu et al., 2005). Certaines études ont également noté des performances altérées en reconnaissance – l'impression subjective, sans référence contextuelle, d'avoir récemment expérimenté un stimulus – qu'il soit question de matériel verbal (Ally, Gold, & Budson, 2009 ; Bennett, Golob, Parker, & Starr, 2006 ; Perri et al., 2005 ; Wolk, Signoff, & DeKosky, 2008) ou de matériel non verbal (Dudas et al., 2005). Une faiblesse aux épreuves de reconnaissance suggère que les atteintes vont au-delà de la récupération, et qu'elles touchent plus probablement l'encodage (et/ou la consolidation). En revanche, la reconnaissance s'est montrée intacte dans certaines études (Anderson et al., 2008 ; Hudon, Belleville, & Gauthier, 2009 ; Serra et al., 2010 ; Westerberg et al., 2006), et il semble que ce soit plus fréquemment dans les études qui utilisaient du matériel verbal ; la reconnaissance du matériel non verbal se montre plus systématiquement altérée (Belleville et al., 2008). L'encodage pourrait donc être atteint, mais apparaître préservé sous certaines conditions.

Hudon, Villeneuve et Belleville (2011) viennent appuyer une atteinte de l'encodage, puisqu'ils ont démontré qu'une manipulation des conditions d'encodage, via l'ajout d'indices sémantiques, mettait en évidence un déficit de rappel chez les individus avec TCL, comparativement aux individus âgés sains. Or, l'étude a parallèlement mis en lumière que, malgré qu'ils n'en bénéficiaient pas autant que les individus sains, cet ajout d'indices sémantiques permettait d'améliorer significativement la performance de rappel libre chez les individus avec TCL. Cela suggère que ces personnes peuvent être aidées par un support à l'encodage, une caractéristique qui les rend susceptibles de bénéficier d'un entraînement portant sur les stratégies d'encodage. Aussi, l'atteinte moins fréquente de la reconnaissance de matériel épisodique verbal (vs non verbal) pourrait traduire le fait que l'encodage qui repose sur des informations sémantiques aide la reconnaissance. En effet, le matériel verbal est plus souvent connu et sémantiquement significatif (e.g., mots), tandis que le matériel non verbal est rarement connu ou signifiant (e.g., visages inconnus). En somme, il semble que les personnes avec TCL puissent bénéficier d'indices sémantiques lors de l'encodage, et ainsi montrer un meilleur rappel libre ou une meilleure reconnaissance. Il apparaît donc qu'enseigner des stratégies favorisant un encodage plus riche et élaboré pourrait les aider.

1.1.4.2. Le contrôle attentionnel

Outre l'atteinte de mémoire épisodique, il apparaît que certaines atteintes du contrôle attentionnel soient également présentes chez les personnes avec TCL. Le contrôle attentionnel peut être considéré comme un système exécutif dont le rôle est de guider les actions, et de maintenir ou supprimer les informations de la conscience (Engle, 2002). Miyake et ses collaborateurs (2000), pour leur part, décrivent le contrôle attentionnel comme un système de contrôle exécutif regroupant trois fonctions relativement indépendantes, soit l'inhibition, la mise à jour et l'alternance. Des études ont mis en évidence des déficits de contrôle attentionnel dans le TCL. En particulier, plusieurs études ont rapporté une diminution de la résistance à l'interférence (Bélanger & Belleville, 2009 ; Bélanger, Belleville, & Gauthier, 2010 ; Traykov et al., 2007; Borella et al., 2017) ou dans la capacité à inhiber des stimuli externes non pertinents (Drzezga et al., 2005). Par exemple, les personnes avec TCL peuvent montrer des atteintes sur une tâche de dénomination de couleurs exigeant d'inhiber une réponse automatique de lecture (Bélanger, Belleville, & Gauthier, 2010 ; Traykov et al., 2007), ou sur une tâche de rappel de mots en contexte d'interférence proactive (Borella et al., 2017). Sur le plan cérébral, Drzezga et ses collègues ont montré que les personnes avec TCL montraient moins de désactivation cérébrale dans les aires auditives lors d'une tâche visuelle comparativement aux personnes sans TCL, ce phénomène étant interprété par les auteurs comme traduisant un déficit d'inhibition des informations auditives non pertinentes à la tâche en cours. Les auteurs concluent que les personnes avec TCL ne suppriment pas adéquatement le traitement des stimuli auditifs lors d'une tâche visuelle. Une étude suggère de même que le TCL amnésique à domaines multiples, un sous-type très étudié, soit toujours caractérisé par au moins une atteinte exécutive, l'inhibition étant la fonction la plus souvent atteinte (Johns et al., 2012). De surcroît, comparativement à des personnes âgées saines, il appert que les individus avec TCL rapportent être davantage sensibles à l'interférence dans la vie de tous le jours (Clément, Belleville, & Gauthier, 2008).

En somme, un bon programme d'entraînement cognitif chez les gens en phase prodromique de la MA gagnerait à viser non seulement la mémoire, mais aussi l'amélioration du contrôle attentionnel, plus particulière l'inhibition.

1.2. L'intervention cognitive

1.2.1. Définition

Il existe différents modes d'intervention visant l'amélioration de la cognition. Clare et Woods (2004) proposent une nomenclature afin de les distinguer. Les auteurs réfèrent à trois types, soit la stimulation cognitive, la réhabilitation cognitive et l'entraînement cognitif. La *stimulation cognitive* réfère à la participation à diverses activités non spécifiques ayant pour objectif l'amélioration du fonctionnement cognitif et/ou social. Par exemple, la participation à un groupe de discussion se classe dans cette catégorie. Ensuite, la *réhabilitation cognitive* consiste à cibler les difficultés fonctionnelles spécifiques d'un individu, pour ensuite lui enseigner des stratégies visant à compenser ces difficultés. L*'entraînement cognitif* consiste quant à lui en l'acquisition et la pratique guidée de stratégies ayant un support empirique, à l'aide d'une ou de différentes tâches cognitives. L'acquisition et l'utilisation de ces stratégies peut viser l'optimisation d'une ou de plusieurs fonctions cognitives. L'entraînement est alors qualifié d'uni-factoriel ou de multifactoriel respectivement. Les tâches servant à l'entraînement sont généralement de type « papier-crayon » ou informatisé, mais peuvent également mimer des activités de la vie quotidienne. L'entraînement cognitif a le potentiel de compenser les difficultés cognitives et/ou encore de restaurer une fonction atteinte chez un individu.

Parmi ces différents types d'interventions, l'entraînement cognitif s'avère particulièrement approprié pour les personnes en phase prodromique de la MA (Belleville, 2008). D'abord, la quasi-absence d'impacts fonctionnels chez cette population rend moins pertinente la réhabilitation cognitive, qui vise particulièrement la réduction de ces impacts. Ensuite, l'entraînement cognitif, contrairement aux autres types d'intervention, permet de cibler spécifiquement l'amélioration des fonctions cognitives d'intérêt chez ces individus, soit ici la mémoire et l'inhibition. Enfin, nous savons que les individus avec TCL ou DCS ont la capacité d'apprendre l'utilisation de nouvelles stratégies, étant donné que leurs atteintes cognitives demeurent légères (dans le TCL) ou absentes (dans le DCS).

1.2.2. Entraînement cognitif dans le vieillissement

L'entraînement cognitif a été largement étudié afin de déterminer s'il permettait d'améliorer la cognition dans le vieillissement. Différentes fonctions ou activités cognitives ont fait l'objet d'entraînement, dont le contrôle attentionnel et exécutif (Kramer, Larish, & Strayer 1995 ; Bherer et al., 2005 ; Bherer et al., 2008 ; Dahlin, Neely, Larsson, Bäckman, & Nyberg, 2008 ; Gagnon et Belleville, 2012 ; Bier, De Boysson, & Belleville, 2014), l'attention sélective (Willis et al., 1983 ; Mozolic, Long, Morgan, Rawley-Payne, & Laurienti, 2011 ; Wilkinson, & Yang, 2012 ; 2015), la vitesse de traitement (Vance et al., 2007 ; Edwards et al., 2002 ; Roenker Cissell, Ball, Wadley, & Edwards, 2003 ; Edwards et al., 2005), la perception (Barnes et al., 2009 ; Rosen, Sugiura, Kramer, Whitfield-Gabrieli, & Gabrieli, 2011) la mémoire de travail (Buschkuehl et al., 2008 ; Li et al., 2008 ; Richmond et al., 2011 ; Brehmer, Westerberg & Bäckman, 2012) et la mémoire épisodique (Belleville et al., 2006 ; Ball et al., 2002). De nombreuses revues et méta-analyses attestent de l'efficacité de ces entraînements, tant chez les personnes âgées saines (Verhaeghen et al., 1992 ; Gross et al., 2012 ; Lampit, Hallock, & Valenzuela, 2014 ; Lustig, Shah, Seidler, & Reuter-Lorenz, 2009 ; Kelly et al., 2014 ; Simons et al., 2016) que celles avec TCL (Belleville, 2008 ; Jean, Bergeron, Thivierge, & Simard, 2010 ; Stott & Spector, 2011 ; Gates et al., 2011 ; Simon, Yokomizo, & Bottino, 2012).

Étant donné que la mémoire épisodique et l'attention sont parmi les premières fonctions atteintes dans les stades prodromiques de la MA, et puisque que ce sont les interventions sur lesquelles porte ce travail, la prochaine section de l'introduction présentera les études d'intervention portant sur ces fonctions cognitives.

1.2.3. Entraînement de la mémoire épisodique

L'entraînement cognitif visant la mémoire épisodique implique habituellement l'enseignement de diverses stratégies permettant de soutenir les processus d'encodage et/ou de récupération (Willis & Belleville, 2016 ; Clare & Woods, 2004 ; Gross et al., 2012 ; Verhaeghen, 2016). La répétition, l'élaboration sémantique, la catégorisation, l'organisation sont des exemples de stratégies de mémorisation qui peuvent s'appliquer à différents types de matériel ou de tâche. D'autres stratégies se basent plutôt sur l'imagerie mentale et s'appliquent à des types de matériels plus ciblés. C'est le cas par exemple de l'association nom-visage, qui sert à mémoriser quels noms sont liés aux bons visages, ou la méthode des lieux, qui permet de mémoriser des listes d'items ordonnés en associant ceux-ci à des points de repère situés sur une route mentale.

1.2.3.1. Dans le vieillissement normal

Un nombre impressionnant d'études a mis en évidence que des entraînements aux stratégies mnésiques peuvent avoir un impact positif sur la performance de mémoire épisodique dans le vieillissement normal (e.g., Robertson-Tchabo, Hausman & Arenberg, 1976 ; Yesavage, 1983 ; Yesavage & Rose, 1983 ; Yesavage & Rose, 1984a ; Yesavage & Rose, 1984b ; Anschutz et al., 1985 ; Hill, Sheikh & Yesavage, 1987 ; Hill et al., 1989 ; Kliegl, Smith, & Baltes, 1989 ; Rebok & Balcerak, 1989 ; Ball et al., 2002 ; Willis et al., 2006 ; Smith et al., 2009). Globalement, une méta-analyse (Verhaeghen et al., 1992) a démontré qu'un entraînement de la mémoire épisodique menait à un gain moyen de performance de 0,64 écart-type sur les tâches cibles, c'est-à-dire très similaires aux tâches entraînées ou faisant appel à la fonction cognitive entraînée. Pour ce qui était des gains sur des tâches non entraînées, ils n'étaient pas supérieurs à ceux observés chez des groupes de contrôle n'ayant pas reçu l'intervention.

Parmi ces études, certaines interventions étaient uni-factorielles, c'est-à-dire qu'elles visaient l'entraînement unique de la mémoire épisodique. Parmi celles-ci, quelques-unes étaient basées sur une stratégie formelle unique telle que la méthode des lieux (Robertson-Tchabo et al., 1976 ; Yesavage & Rose, 1983 ; Anschutz et al., 1985 ; Kliegl et al., 1989 ; Rebok & Balcerak, 1989 ; Engvig et al., 2010 ; Engvig et al., 2012) ou l'association nom-visage (Yesavage, 1983 ; Yesavage & Rose,1984a ; Hill et al., 1987 ; Hill et al., 1989). À titre d'exemple, Robertson-Tchabo et al. (1976) ont montré que 5 séances d'apprentissage de la méthode des lieux menaient à une amélioration significative de la performance dans une épreuve de rappel de mots, comparativement à une condition contrôle active consistant à créer et mémoriser une route mentale. Concernant la stratégie d'association nom-visage, l'étude de Yesavage et Rose (1984a) a montré que 2 séances d'entraînement pouvaient améliorer le rappel de noms propres chez des personnes âgées.

D'autre part, certaines études ont porté sur plusieurs stratégies de mémoire, comme dans le cas de l'étude ACTIVE (Advanced Cognitive Training for Independent and Vital Elderly ; Jobe et al., 2001 ; Ball et al., 2002), le plus grand essai contrôlé/randomisé ayant été réalisé à ce jour chez les personnes âgées saines. Spécifiquement, 2832 personnes âgées sans trouble cognitif étaient randomisées en quatre groupes, dont trois impliquaient un entraînement cognitif (visant soit la mémoire, le raisonnement, ou la vitesse de traitement) et un constituait un groupe de contrôle sans contact. Parmi eux, 771 individus ont participé aux dix séances de la condition impliquant un entraînement de la mémoire. Par la suite, elles montraient des performances plus élevées sur des tâches de rappel de mots, comparativement au groupe de contrôle sans contact et par rapport aux autres groupes d'intervention. Ainsi, l'efficacité d'un entraînement mnésique uni-factoriel avec stratégies multiples chez les aînés est bien démontrée par l'étude ACTIVE. Ces effets étaient même maintenus après cinq ans (Willis et al., 2006). Aucun effet de l'entraînement mnésique n'a par ailleurs été observé dans d'autres domaines cognitifs ou encore dans la vie quotidienne. De façon intéressante, il y avait toutefois un effet de l'entraînement mnésique sur la vie quotidienne dix ans suivant l'intervention (Rebok et al., 2014).

Les études multifactorielles utilisaient plutôt l'enseignement d'une stratégie de mémoire couplé à des entraînements visant d'autres fonctions cognitives ou psychologiques. Des stratégies de mémoire telles que l'association nom-visage ou la méthode des lieux ont ainsi été enseignées en combinaison avec des exercices de jugement, de relaxation, d'amélioration de l'attitude ou d'initiation à l'imagerie mentale (Yesavage, 1983 ; Yesavage, Rose & Bower, 1983 ; Yesavage, 1984 ; Yesavage & Rose, 1984b ; Yesavage, Sheikh, Tanke, & Hill, 1988 ; Yesavage, Sheikh, Friedman, & Tanke, 1990 ; Gratzinger et al., 1990). La conclusion générale qui émane de ces travaux est que l'efficacité des stratégies mnésiques peut être améliorée grâce à l'ajout d'exercices préalables relatifs à l'imagerie mentale, à l'élaboration sémantique, et/ou suite à une réduction de l'anxiété.

Selon la méta-analyse de Gross et ses collaborateurs (2012), 71 % des entraînements de la mémoire utilisent une combinaison de différentes techniques et stratégies, que ce soit dans des entraînements uni-factoriels ou multifactoriels. Il semble que l'utilisation de méthodes multiples maximise les bénéfices de l'entraînement (Verhaeghen et al., 1992 ; Gross et al., 2012).

1.2.3.2. Chez la personne âgée à risque de développer la MA

Plusieurs études attestent de l'efficacité de l'entraînement de la mémoire épisodique chez les personnes avec TCL (voir Belleville, 2008 ; Jean et al., 2010 ; Belleville, Boller, & Prieto del Val, 2016 ; pour des revues).

Certaines études ont utilisé un entraînement cognitif uni-factoriel. Par exemple, l'apprentissage d'une stratégie d'association de noms et de visages, basée sur l'imagerie mentale interactive, a permis d'améliorer la mémoire associative de 3s dans une tâche de reconnaissance à choix forcés (Hampstead, Sathian, Moore, Nalisnick, & Stringer, 2008 ; Hampstead et al., 2011). Le même type de technique d'imagerie interactive s'est avérée efficace pour améliorer la mémoire associative entre des lieux et des objets (Hampstead, Stringer, Stilla, Giddens, & Sathian, 2012).

La majorité des études ont cependant misé sur des interventions mnésiques multifactorielles, qui consistent essentiellement en l'enseignement de diverses stratégies mnésiques en combinaison avec la présentation d'informations sur la mémoire et/ou sur l'hygiène de vie. Les stratégies mnésiques enseignées comprennent le plus souvent l'imagerie interactive (e.g., la méthode des lieux, l'association nom-visage), l'apprentissage sans erreur, de même que la catégorisation, l'organisation et l'association sémantique. Les interventions sont souvent enrichies de diverses composantes, comme des tâches de contrôle attentionnel (Belleville et al., 2006 ; Belleville et al., 2011), des exercices de contrôle exécutif (Sugano et al., 2012), des exercices de stimulation en groupe (Buschert et al., 2011), des exercices moteurs (Kurz, Pohl, Ramsenthaler, & Sorg, 2009), des exercices en lien avec les activités quotidiennes (Lim et al., 2012 ; Tappen & Hain, 2014), des exercices portant sur l'utilisation d'aides externes (Kinsella et al., 2009) ou de la psychoéducation sur la mémoire (Olchik, Farina, Steibel, Teixeira, & Yassuda, 2013). Certaines études ont aussi montré une amélioration de la mémoire épisodique dans le TCL en utilisant des interventions multifactorielles informatisées visant soit la mémoire et l'attention (Herrera, Chambon, Michel, Paban, & Alescio-Lautier, 2012), une combinaison de plusieurs fonctions cognitives (mémoire, langage, attention, etc.) (Rozzini et al., 2007 ; Talassi et al., 2007) ou la vitesse et la précision du traitement auditif (Rosen, Sugiura, Kramer, Whitfield-Gabrieli, & Gabrieli, 2011). Enfin, une étude récente (Belleville et al., 2018) a démontré qu'une intervention cognitive enseignant des stratégies mnésiques et attentionnelles variées améliorait non seulement la performance de mémoire des individus avec TCL, mais également leur usage de stratégies au quotidien. Les effets étaient maintenus six mois plus tard. L'intérêt de cette étude réside surtout dans le fait que ces effets étaient absents chez les groupes de contrôle passif (sans contact) et actif (intervention psychosociale), suggérant que les améliorations notées étaient bel et bien attribuables à l'intervention cognitive, et non à un effet de pratique et/ou au fait de participer à des séances en groupe.

En somme, il semble que les interventions multifactorielles soient efficaces pour améliorer la mémoire épisodique dans le TCL. Leur force est sans contredit qu'elles présentent un grand éventail de stratégies permettant l'amélioration de la mémoire dans différentes situations et pour différents types de matériel (e.g., visages, liste de mots ou d'items, etc.). Par contre, vu le nombre varié de tâches utilisées et le grand nombre de fonctions visées par ces entraînements, il est difficile de déterminer les ingrédients actifs des interventions. Autrement dit, ces protocoles ne permettent pas de spécifier quelles stratégies contribuent aux améliorations cognitives obtenues ; certains éléments pourraient être particulièrement utiles, alors que d'autres pas du tout.

Les résultats intéressants suite à l'entraînement d'une stratégie de mémoire unique basée sur imagerie interactive mettent en lumière une faiblesse des entraînements multifactoriels : ils ne mesurent pas la contribution de chaque stratégie enseignée aux améliorations cognitives subséquentes. Par exemple, la méthode des lieux est une stratégie mnésique basée également sur l'imagerie mentale et qui est très souvent présente dans les interventions multifactorielles dans le TCL. Par contre, son efficacité spécifique n'a jamais été mesurée dans cette population. Précisément, la méthode des lieux sert à mémoriser des listes ordonnées d'items. Son utilisation demande d'abord l'identification d'une route mentale bien connue et l'apprentissage de points de repères ordonnés sur la route choisie. Celle-ci est donc constituée d'une série de points de repères (i.e., lieux) positionnés dans un endroit connu de l'utilisateur de la stratégie (p.ex. sa maison, sa ville de résidence). Ces lieux pourront être visités mentalement dans leur ordre d'apparition sur la route. Dans un deuxième temps, l'utilisateur se sert de l'imagerie mentale interactive afin de relier chaque item à mémoriser à un point de repère, en suivant l'ordre de la route mentale. Par exemple, si le premier item d'une liste à mémoriser est le mot *chat* et que le premier point de repère de la route mentale est un *fauteuil*, l'utilisateur pourrait imaginer un chat qui griffe le fauteuil. Finalement, lors de la récupération, l'utilisateur doit revisiter mentalement – et dans l'ordre – chaque point de repère de sa route mentale où il retrouvera les images créées et les items correspondants (Bower, 1970 ; Gilbert et al., 2008 ; Gross et al., 2014 ; Verhaeghen, 2016). Cette stratégie a l'avantage de pouvoir être utilisée dans plusieurs tâches de la vie quotidienne (il suffit qu'elle comporte une liste d'items concrets : p.ex. rappel de listes d'épicerie, de rendez-vous, de tâches, etc.), contrairement à l'association nom-visage, qui ne peut être utile que pour l'apprentissage bien précis de noms de personnes. La méthode des lieux a aussi comme caractéristique de favoriser l'encodage de matériel épisodique en misant sur l'ajout d'indices sémantiques, une technique connue pour améliorer le rappel chez les individus avec TCL. Bref, cette stratégie serait tout indiquée pour un entraînement uni-factoriel dans les stades prodromiques de la MA.

Des études d'entraînements de la mémoire ciblant spécialement les individus avec plainte mnésique ont aussi montré des résultats positifs, mais ils sont relativement rares et se limitent à l'observation d'effets sur les tâches entraînées. Par exemple, l'étude de Scogin, Storandt et Lott (1985) témoigne du fait que les aînés se plaignant de leur mémoire puissent améliorer leur rappel de mots ou d'associations nom-visage suite à l'apprentissage de diverses stratégies mnésiques. Aucun effet n'était observé sur d'autres tâches non entraînées telles que le rappel d'une liste d'achats, un rappel de chiffres ou un test de mémoire et de perception visuelle. De plus, l'entraînement n'a eu aucun effet sur l'intensité de la plainte de mémoire ou sur l'importance des symptômes dépressifs des participants. Tsai, Yang, Lan et Chen (2008) rapportent des résultats similaires, montrant que les personnes âgées avec plainte mnésique ont montré une augmentation de leur performance de mémoire verbale suite à une intervention visant cette même fonction. De façon très intéressante, Engvig et ses collaborateurs (2012 ; 2014) montrent l'efficacité spécifique d'un entraînement à la méthode des lieux chez les personnes avec plainte mnésique. D'abord, les deux études mettent en lumière que les participants ont un meilleur rappel de mots suite à l'intervention. De plus, il apparaît que l'intervention accroisse le volume de structures cérébrales clées pour le bon fonctionnement de la mémoire épisodique, telle que l'hippocampe (Engvig et al., 2012 ; 2014) et le lobe préfrontal (Engvig et al., 2014). En définitive, en plus d'être une stratégie dont l'utilisation semble très pertinente dans le TCL, la méthode des lieux semble une intervention hautement efficace pour les individus se plaignant de difficultés de mémoire.

1.2.4. Entraînement attentionnel dans le vieillissement

Plusieurs études supportent la plasticité du contrôle de l'attention dans le vieillissement normal et ont montré que ces fonctions peuvent être améliorées suite à un entraînement cognitif (Kramer, Larish, & Strayer, 1995 ; Bherer et al., 2005 ; Bherer et al., 2008 ; Bier et al., 2014 ; Lussier, Gagnon, & Bherer, 2012 ; Bier, Ouellet, & Belleville, 2018). La plupart ont porté sur l'entraînement de l'attention divisée, c'est-à-dire sur la modulation de l'allocation des ressources attentionnelles entre différentes tâches réalisées simultanément. Par exemple, l'intervention de Bier et al. (2014) demandaient aux participants de réaliser deux tâches concurrentes, soit la détection d'une barre rouge et la résolution d'une équation alphanumérique. Les participants se trouvant dans une condition d'entraînement d'attention VARIABLE – soit exigeant qu'une « quantité » d'attention dédiée à chaque tâche soit modulée en fonction d'une consigne – ont amélioré significativement leur capacité à moduler leur attention entre les deux tâches. Des gains sur des tâches de mémoire de travail non entraînées ont également été constatés (Bier et al., 2014). Une seule étude semble avoir misé sur un entraînement spécialisé de l'attention chez la personne à risque de démence, soit un entraînement au contrôle attentionnel en contexte de double-tâche (Gagnon & Belleville, 2012). Cet entraînement a permis d'améliorer l'attention focalisée, la vitesse de traitement, et la flexibilité mentale chez des individus avec TCL.

L'attention sélective – qui réfère à la capacité de diriger son attention sur les informations pertinentes à la tâche, tout en inhibant les stimuli non pertinents (Neill, Valdes, & Terry, 1995) – a également fait l'objet de quelques études d'entraînement cognitif chez les personnes âgées. L'entraînement de cette fonction a parfois été intégré dans un entraînement visant également d'autres fonctions attentionnelles, telles que la discrimination, la flexibilité et la concentration (Willis et al., 1983), ou encore a été réalisé isolément en focalisant sur l'inhibition cognitive (Wilkinson, & Yang, 2012 ; 2015). Ces études incluaient en fait un entraînement de l'inhibition puisque les participants devaient se pratiquer à ignorer certaines caractéristiques d'un stimuli, pour se concentrer sur d'autres. Par exemple, dans l'intervention décrite par Willis et ses collaborateurs (1983), les participants s'exerçaient à compter rapidement des étoiles et des points d'une couleur donnée en ignorant la forme, ou d'une forme donnée en ignorant la couleur. Par la suite, les individus entraînés affichaient une meilleure performance à une tâche d'inhibition proche de celle entraînée. L'intervention de Wilkinson et Yang (2012) travaillait pour sa part l'inhibition de façon spécifique en utilisant un protocole classique de Stroop ; les participants s'exerçaient à inhiber la lecture de mots de couleur, pour plutôt nommer la couleur de l'encre avec laquelle ils étaient imprimés. La tâche de Stroop s'est vue améliorée et les bénéfices étaient maintenus trois ans plus tard (Wilkinson et Yang, 2015).

Une seule étude s'est spécifiquement intéressée à l'entraînement de l'inhibition de distracteurs auditifs (Mozolic et al., 2011). Les participants complétaient différents exercices visuels (détection, identification, classification ou séquençage de lettres, de mots ou de chiffres) en présence de distracteurs auditifs verbaux (p.ex. bruit de tonnerre, de circulation automobile, d'animaux, etc.). Le niveau de difficulté était augmenté en fonction de la performance des participants, via la modification du niveau de distractibilité des stimuli. La modification du niveau de distractibilité était basée sur une étude pilote précédente ayant permis de classer les différents bruits selon leur niveau de difficulté. La performance aux tâches visuelles a significativement été améliorée suite à l'intervention. Cette étude suggère que l'entraînement peut permettre aux personnes âgées d'améliorer leur capacité à réaliser des tâches d'inhibition de distracteurs auditifs. Comme la mémorisation dans la vie de tous les jours se fait souvent dans des environnements bruyants, l'ajout d'un entraînement à l'inhibition auditive à un entraînement mnésique pourrait aider les aînés à transférer les améliorations mnésiques du laboratoire jusqu'en contexte réel. Or, un entraînement cognitif visant à la fois la mémoire et l'inhibition en interaction n'a jamais été testé ; nous ne savons pas pour l'instant s'il est à même d'améliorer la capacité de mémorisation en contexte de bruit chez les personnes âgées.

1.3. Le transfert

Il est important de garder en tête que le but ultime des interventions cognitives est le transfert des bénéfices cognitifs au quotidien, afin d'améliorer la qualité de vie des personnes âgées.

1.3.1. Définition

La notion de transfert prend racine dans la *théorie des éléments identiques* (*identical elements theory*), proposé par Thorndike et Woodworth (1901). Cette théorie soutenait qu'un apprentissage pouvait se généraliser – c'est-à-dire se transférer – à d'autres activités non directement visées par l'apprentissage, si ces activités possédaient certains éléments communs avec l'apprentissage initial.

Différents types de transfert sont actuellement décrits au sein de la littérature. Bon nombre d'auteurs ont proposé la distinction entre le transfert *proche* (near transfer) et le transfert *éloigné* (far transfer) (Perkins & Salomon, 1992 ; Woltz, Gardner, & Gyll, 2000 ; McGinnis, 2016). Il s'agit alors de déterminer si le transfert porte sur des tâches ou situations qui se ressemblent, ou qui diffèrent sur bon nombre de caractéristiques. L'opposition entre transfert proche et éloigné peut reposer sur les caractéristiques associées au matériel utilisé et/ou à l'environnement où l'apprentissage est appliqué (Barnett & Ceci, 2002). Toutefois, cette opposition entre transfert proche et éloigné a été critiquée. En effet, il n'existe pas de critères précis permettant de déterminer si une tâche est proche ou éloignée de celle entraînée, ce qui a mené à une grande disparité d'application de ces concepts dans la littérature, selon le jugement des chercheurs (Simons et al., 2016). Par exemple, certains auteurs ont fait référence à la notion de transfert éloigné suite à un entraînement en attention divisée quand la tâche de transfert modifiait la modalité d'entrée et de réponse (Lussier et al., 2012), quand elle mesurait la mémoire de travail (Bier et al., 2014) ou quand elle mesurait le fonctionnement quotidien (Mowszowski, Lampit, Walton, & Naismith, 2016).

Certains auteurs ont plutôt proposé de distinguer le *contenu* et le transfert de *contexte* (Barnett & Ceci, 2002). Le transfert de contenu se produit lorsqu'un apprentissage permet d'améliorer une habileté non directement visée par l'entraînement, mais partageant des processus cognitifs communs avec la ou les tâches entraînées. Dans le cadre de cette thèse, le transfert de contenu se définit comme celui mesuré en laboratoire à l'aide des tâches expérimentales ou cliniques mesurant des processus cognitifs proches de ceux entraînés. Le transfert de contexte est quant à lui utilisé quand un apprentissage (e.g., une stratégie ou un comportement) réalisé dans un contexte particulier est appliqué avec succès dans un contexte différent de celui où il a eu lieu. Dans le contexte des entraînements mnésiques, on s'intéresse particulièrement au transfert de contexte puisque l'objectif est de faire en sorte que les améliorations se reflètent dans la vie de tous les jours ou que les stratégies apprises soient utilisées hors du laboratoire, dans la vie de la personne.

1.3.2. Transfert des entraînements cognitifs

Comme le but ultime des interventions cognitives dans le vieillissement est de mener à des améliorations dans le quotidien, il est primordial de s'intéresser au transfert de contexte dans le cas des entraînements cognitifs : quelles sont les bénéfices concrets des entraînements pour les aînées, une fois de retour à la maison?

Pour l'instant, les revues ou méta-analyses récentes concluent pour la plupart à une absence de transfert des entraînements cognitifs dans la vie quotidienne (Rebok et al., 2007 ; Simons et al., 2016). Kelly et ses collaborateurs (2014) soulignent pour leur part que l'impact des entraînements cognitifs dans la vie de tous les jours est surtout trop peu investigué.

1.3.2.1. Transfert de contexte des entraînements mnésiques

Si l'on s'attarde particulièrement aux entraînements mnésiques chez les personnes âgées, les études ne sont pas claires à savoir s'il y a bel et bien transfert de contexte. Par exemple, suite à l'étude contrôlée/randomisée portant sur le programme MÉMO+, où plusieurs stratégies de mémoire étaient enseignées, les participants avec TCL rapportaient un usage plus fréquent de stratégies dans leur quotidien. Or, ils ne rapportaient pas d'amélioration dans leur capacité à réaliser diverses activités complexes de la vie quotidiennes (Belleville et al., 2018). Dans le même ordre d'idées, le volet d'entraînement mnésique de l'essai contrôlé/randomisé ACTIVE a mené à une amélioration dans la capacité à accomplir diverses activités de la vie quotidienne, celle-ci étant mesurée par un questionnaire auto-rapporté. Or, cet effet n'a été mis en évidence que dix ans après l'intervention (Rebok et al., 2014). Directement après l'intervention (Ball et al., 2002) ou même cinq ans plus tard (Willis et al., 2006), aucune amélioration n'était présente sur les mesures de transfert de contexte, que ce soit sur des tâches simulant diverses activités ou les questionnaires de fonctionnement quotidien. Kinsella et ses collaborateurs (2009) ont montré que des individus avec TCL obtenaient une meilleure performance à une tâche de mémoire prospective qualifiée de près du quotidien (i.e., se rappeler d'inscrire certaines informations sur une enveloppe en un moment donné) suite à une intervention mnésique. En revanche, l'auto-évaluation que les participants faisaient de leur capacité de mémoire au quotidien demeurait inchangée. D'autres études n'ont pour leur part démontré aucun transfert de contexte suite à un entraînement mnésique chez des individus avec TCL, via l'utilisation de questionnaires portant sur les activités de la vie quotidienne (Lim et al., 2012). Les résultats en matière de transfert dans la vie de tous les jours chez la personne âgée sont donc inconsistants, et ne permettent pas de conclure notoirement à la présence de transfert. La question est maintenant de savoir les raisons qui expliquent les difficultés à mettre de l'avant un transfert de contexte. Les prochaines sections s'attarderont ainsi aux défis inhérents à l'obtention de celui-ci.

1.3.2.2. Mesurer le transfert de contexte

Un premier défi en ce qui a trait à l'obtention d'un transfert de contexte est de savoir le détecter s'il se produit. Pour l'instant, le transfert de contexte est habituellement mesuré à l'aide de questionnaires auto-rapportés (Belleville et al., 2006 ; Kurz et al., 2009 ; Lustig & Flegal, 2008 ; Troyer, Murphy, Anderson, Moscovitch, & Craik, 2008 ; Kinsella et al., 2009 ; Lim et al., 2012 ; Lampit et al., 2014). Les réponses aux questionnaires auto-rapportés sont toutefois très fortement influencées par la mémoire, le jugement, les attentes et l'humeur. Ces questionnaires pourraient donc ne pas refléter objectivement le fonctionnement quotidien et/ou ne pas être sensibles aux interventions parce que nécessitant une autocritique adéquate quant à sa propre performance cognitive quotidienne.

Une autre avenue parfois empruntée pour mesurer le transfert de contexte est l'utilisation de tâches simulant les activités quotidiennes. Par exemple, l'étude ACTIVE (Jobe et al., 2001) utilisait des mesures expérimentales simulant diverses activités de la vie de tous les jours (i.e., trouver un numéro de téléphone dans un bottin, lire les ingrédients sur une boîte de conserve, etc.). Toutefois, ces simulations reproduisent habituellement des tâches plutôt simples et relativement éloignées de la complexité du quotidien. Un des défis de la mesure du transfert réside donc dans la recherche de mesures pertinentes, qui sont à la fois objectives et à même de refléter la complexité des situations de la vie quotidienne.

1.3.2.3. Favoriser le transfert de contexte

Un second défi associé à l'obtention d'un effet de transfert de contexte est de savoir si le contenu des interventions permet effectivement de générer du transfert. En effet, le transfert dépend largement du degré de ressemblance entre les conditions d'entraînements et de transfert (Elangovan & Karakowsky, 1999; Yamnill & McLean, 2001). Cette notion fait directement référence à la *Theory of identical elements* (Thorndike & Woodworth, 1901). En ce qui concerne le transfert de contexte, il est donc supposé que plus le contexte d'intervention est similaire à la vraie vie, plus la probabilité du transfert des acquis au quotidien augmente. Ainsi, il serait favorable de proposer aux participants des exercices réalisés dans un contexte ressemblant le plus possible à celui où ils devront appliquer leurs apprentissages dans le futur (Elangovan & Karakowsky, 1999 ; York, 2003). Autrement dit, il est ici question d'améliorer la validité écologique des conditions d'entraînements.

Les entraînements cognitifs actuels présentent certaines lacunes sur le plan de la validité écologique, plus particulièrement sur le plan de la vérisimilitude, qui réfère au degré de similitude entre les demandes d'une condition expérimentale et les demandes de l'environnement (Franzen & Wilhelm, 1996). D'une part, l'environnement quotidien où les stratégies cognitives apprises doivent être utilisées est peu similaire au laboratoire, où l'entraînement cognitif est réalisé. En effet, l'apprentissage se fait habituellement en classe, en position assise, alors que le participant peut utiliser un papier et un crayon. L'environnement est propice à la mémorisation, exempt de distractions. Nous sommes donc bien loin de la complexité et de la richesse d'une tâche de mémoire quotidienne, où la personne doit souvent concurremment gérer les distractions environnantes, interagir avec des objets et/ou se déplacer dans son environnement. D'autre part, la performance de mémoire dans la vie quotidienne dépend en grande partie du contrôle de l'attention, puisqu'elle se réalise régulièrement en situation de bruit ambiant non pertinent, qu'il est utile d'ignorer. Autrement dit, la mémoire et l'inhibition sont utilisées en interaction au quotidien. Or, les interventions visent habituellement exclusivement la mémoire ou l'attention ou encore entraînent les deux fonctions de manière séquentielle dans un entraînement multifactoriel (e.g., Belleville et al., 2006). En somme, il semble que le degré de similitude entre les demandes des conditions expérimentales d'entraînement et les demandes de l'environnement de la personne soit faible. La prochaine section exposera maintenant comment les nouvelles technologies peuvent contribuer à contourner certains défis liés au manque de validité écologique du contexte d'intervention.

1.4. La réalité virtuelle

1.4.1. Définition

La RV est une technologie informatisée permettant à un utilisateur d'interagir avec un environnement multi-sensoriel simulé et en trois dimensions (Saposnik & Levin, 2011). L'utilisation de la RV dans le domaine de l'intervention suscite un très grand intérêt puisque la RV permet de simuler divers environnements réels et complexes (Rizzo, Schultheis, Kerns, & Mateer, 2004). Comme nous le verrons plus loin, l'utilisation de la RV dans les interventions cognitives pourrait pallier certaines lacunes de validité écologique et ainsi mieux favoriser le transfert des gains dans la vie quotidienne. L'emploi de tâches en RV comme tâche de transfert pourrait également permettre de mesurer plus adéquatement l'impact des interventions dans des situations proches du quotidien.

Il existe différents systèmes de RV (Biocca & Delaney, 1995), ceux-ci offrant différents degrés d'*immersion* et d'*interaction*. L'immersion réfère à la capacité qu'a la technologie d'offrir un environnement virtuel englobant, qui isole l'utilisateur des sensations du monde réel, dont les stimulations se font à travers une ou plusieurs interfaces sensorielles et dont les représentations sont riches et réalistes (Slater & Wilbur, 1997). Autrement dit, plus le système mène l'utilisateur dans un environnement réaliste et englobant, plus l'immersion est grande. Par exemple, les systèmes de RV qui présentent le monde virtuel sur un écran d'ordinateur (*Window system*) ou les systèmes « miroirs » (*Mirror System*) qui projettent l'environnement virtuel sur un écran et où l'utilisateur voit une image de lui-même en train d'y naviguer offrent un niveau d'immersion limitée, n'isolant pas l'utilisateur du monde réel. D'autres systèmes offrent un niveau d'immersion intermédiaire. C'est le cas de celui utilisant un « véhicule » où prend place le participant, combiné à un écran où le monde virtuel est projeté (*Vehicule-based system*). À l'opposé sur le plan de l'immersion, le système de RV immersive (*Immersive VR system*) fonctionne à l'aide d'un visiocasque stéréoscopique (*Head-Mounted Display*, HMD), qui immerge complètement l'utilisateur dans le monde virtuel. Ce dernier système est celui offrant le plus grand niveau d'immersion.

Un système de RV offre aux utilisateurs différents degrés d'interaction motrice ou sensori-motrice avec l'environnement virtuel. Les interfaces motrices les plus simples utilisent le déplacement via un clavier, une souris, un *trackpad* ou un joystick. D'autres systèmes permettent de se déplacer dans le monde virtuel grâce à un tapis roulant omnidirectionnel. Avec l'utilisation d'un HMD, la marche réelle dans la salle d'immersion peut aussi être utilisée. Dans ce cas, des caméras captent les mouvements de l'utilisateur et ajuste l'environnement perçu en fonction des déplacements. Il existe de même diverses techniques permettant de saisir des objets virtuels. Par exemple, certaines offrent la possibilité de sélectionner et cliquer sur l'objet pour le saisir (à l'aide d'un joystick, d'une souris, etc.) alors que d'autres permettent d'utiliser un gant électronique, qui mime les sensations de prise des objets.

La RV permet de créer des tâches, des environnements et des situations qui ressemblent à des activités de la vie de tous les jours, en faisant l'économie de certaines contraintes posées par les expérimentations en milieu réel. Elle offre un milieu sécuritaire et contrôlé. Elle permet de réaliser des situations complexes proches de la vie de tous les jours sans besoin de déplacer les participants hors du laboratoire. La RV offre donc la possibilité d'augmenter la validité écologique des mesures ou des entraînements cognitifs. Elle peut être utilisée pour entraîner une fonction cognitive, ce qui permet d'augmenter la vérisimilitude de l'entraînement. Elle peut aussi être utilisée comme mesure de transfert, et ainsi améliorer la véridicalité de la mesure, c'est-à-dire le degré avec lequel les performances mesurées sont empiriquement reliées au fonctionnement quotidien.

1.4.2. Utilisation de la RV en évaluation cognitive

Bien que la RV ait été peu utilisée pour mesurer l'efficacité d'un entraînement cognitif chez les personnes âgées, quelques études récentes ont mis en lumière la faisabilité et la validité d'outils d'évaluation cognitif en RV chez les aîné sains, atteints de TCL ou de MA. Ainsi, des mesures en RV ont été construites et utilisées pour évaluer la mémoire spatiale (Moffat, Zonderman & Resnick, 2001 ; Cushman, Stein, & Duffy, 2008 ; Head & Isom, 2010 ; Bellassen, Iglói, de Souza, Dubois, & Rondi-Reig, 2012), la mémoire des objets (Parsons & Rizzo, 2008 ; Sauzéon et al., 2012 ; Sauzéon, N'Kaoua, Pala, Taillade, & Guitton, 2016 ; Sauzéon et al., 2016), la mémoire épisodique associative (Plancher, Gyselinck, Nicolas, & Piolino, 2010 ; Plancher, Tirard, Gyselinck, Nicolas, & Piolino, 2012 ; Jebara, Orriols, Zaoui, Berthoz, & Piolino, 2014), la mémoire prospective (Farrimond, Knight, & Titov, 2006), le fonctionnement exécutif (Boucher, 2014 ; Cipresso et al., 2014) ou la capacité multitâches (Craik & Bialystok, 2006). Des outils en RV ont également été développés afin d'évaluer la capacité des aînés à réaliser des tâches quotidiennes variées (e.g., préparer un repas, prendre l'autobus, trouver et acheter des produits à l'épicerie, etc.) (Atkins et al., 2015) ou spécifiques telles que la conduite automobile (Rizzo et al., 1997 ; Rizzo et al., 2001), la préparation d'une tasse de café (Allain et al., 2014), la préparation d'un repas (Vallejo et al., 2017).

Parmi ces études, celles du groupe de Piolino sont particulièrement intéressantes (Plancher, Gyselinck, Nicolas, & Piolino, 2010 ; Jebara, Orriols, Zaoui, Berthoz, & Piolino, 2014). Par exemple, les participants conduisaient une voiture (i.e., *Vehicule-based system*) dans une ville virtuelle tridimensionnelle présentée sur un écran géant, tout en mémorisant les éléments rencontrés et leur contexte associé. Un rappel libre des éléments et de leur contexte était ensuite demandé. Suite à cette tâche, Plancher et al. (2010) rapportent plusieurs scores plus élevés chez les jeunes que chez les personnes âgées. Les résultats à l'épreuve de RV étaient corrélés à certains aspects des tests classiques de mémoire épisodique verbale et visuelle. Même, l'épreuve en RV semblait plus sensible. Finalement, les résultats obtenus en

RV corrélaient aussi avec l'auto-évaluation que faisaient les participants de leurs difficultés dans la vie quotidienne.

1.4.3. Utilisation de la RV en intervention cognitive

Quelques études ont utilisé la RV pour réaliser des interventions cognitives chez les personnes âgées saines ou à risque de déclin cognitif (voir Coyle, Traynor, & Solowij, 2015, pour une revue). Bien que largement préliminaires, les premiers résultats sont toutefois prometteurs. Ainsi, l'étude de Hofmann et al. (2003) a montré qu'une intervention en RV pourrait mener à des améliorations comportementales et cognitives sur le plan des tâches entraînées. Dans cette étude, des personnes avec la MA devaient s'entraîner à acheter certains produits spécifiques dans un supermarché virtuel, selon un itinéraire précis. Suite à l'intervention, la quantité d'erreurs des participants a diminué, et un maintien des acquis était même observé trois mois après entraînement. De la même manière, 10 séances de jonglerie virtuelle ont mené à l'amélioration des temps de réactions – lors de la jonglerie virtuelle – chez des participants âgés sains (Bisson, Contant, Sveistrup, & Lajoie, 2007). Par contre, ces études ne permettaient pas de déterminer si ces acquis étaient transférés dans une tâche différente ou dans la vie réelle.

Les travaux de Schreiber (1999) et de Man, Chung et Lee, (2012) font état d'une augmentation des performances mnésiques mesurées à l'aide d'épreuves neuropsychologiques chez les personnes avec démence suite à un entraînement en RV. Respectivement, le premier entraînement était basé sur des exercices de mémorisation d'objets et de routes dans un appartement virtuel, alors que le second consistait à pratiquer l'achat de produits dans un magasin virtuel. Dans la même lignée, Gadler, Grassi et Riva (2009) ont montré l'efficacité d'un protocole d'entraînement cognitif visant l'amélioration de l'attention, de la perception et des capacités visuospatiales chez les personnes âgées saines. Au sein de l'étude, les participants étaient exposés à des environnement virtuels près du quotidien, tels qu'un appartement, un supermarché, un parc et un centre commercial. Ils devaient alors se déplacer dans l'environnement et y exécuter différentes tâches. Enfin, Optale et al. (2010) ont soumis des participants âgés présentant des déficits de mémoire soit à une intervention en RV, soit à une intervention contrôle (musicothérapie). Les participants étaient tous exposés à des scénarios présentés auditivement, avec fond musical. Puis, les participants du groupe RV apprenaient à naviguer dans différents environnements virtuels reliés aux précédents scénarios. Suite à l'intervention, les participants du groupe RV ont vu leurs performances de mémoire augmenter, tandis que ceux du groupe contrôle ont plutôt subit un déclin. Cette même intervention a aussi été réalisée de façon préliminaire auprès d'une dame avec une MA débutante. Après 12 séances, la patiente rapportait un meilleur rappel des noms propres et une diminution du manque du mot. Elle affirmait aussi avoir un meilleur sommeil et constatait une diminution de ses maux de tête (Optale et al., 2001).

Une faiblesse majeure des études décrites plus haut est qu'on ne sait pas si l'entraînement virtuel apporte une valeur ajoutée par rapport à un entraînement non-virtuel puisque les deux types d'entraînement n'étaient généralement pas comparés. On peut en effet penser que l'entraînement virtuel améliore la cognition, comme le fait l'entraînement réel mais sans apport particulier. Une autre faiblesse de ces études est que la plupart utilisent des systèmes de type *Window*, présentant l'environnement sur écran d'ordinateur, et étant peu immersifs. La promesse d'un entraînement opéré dans un contexte dit « écologique » n'est donc pas tout à fait rendue.

En somme, des études suggèrent qu'une intervention en RV pourrait avoir un effet positif sur la cognition des personnes âgées. Cependant, les études menées auprès des personnes âgées demeurent encore très rares. De plus certaines questions demeurent. D'abord, les mesures de RV immersive sont-elles appropriées et faisables auprès des aînés, et permettent-elles l'obtention de mesures valides ? Ensuite, la RV peut-elle permettre de mesurer le transfert de contexte ? Enfin, est-ce que le fait d'enrichir un entraînement cognitif classique avec des exercices en RV favorise les effets de transfert de contexte ?

1.5. Conclusion

En conclusion, les aînés se plaignant de leur mémoire ont plus de risques que la population générale de progresser vers la démence. Nous savons maintenant que la mémoire épisodique et le contrôle attentionnel sont parmi les premières fonctions atteintes dans les phases prodromiques de la MA. Si les interventions pour les personnes âgées saines, avec plainte mnésique ou TCL se sont focalisées sur les améliorations de la mémoire, elles ont peu porté sur le contrôle attentionnel ou sur l'interaction entre ces deux composantes. Également, même si les interventions permettent un gain mnésique, celui-ci n'est souvent pas reflété dans des activités proches du fonctionnement quotidien. Ce manque de résultats positifs pourrait s'expliquer d'une part par le manque d'objectivité et de validité écologique des mesures de transfert de contexte. D'autre part, le contexte des interventions manque également de validité écologique du fait qu'il ressemble peu aux conditions de la vie réelle, où la mémorisation doit souvent se faire en situation complexe et/ou bruyante. La RV immersive pourrait pallier ces lacunes par la création de mesures de transfert de contexte objectives et écologiques. De même, elle pourrait permettre de réaliser des interventions plus proches de la vie quotidienne. Enfin, le fait de réaliser un entraînement de la mémoire en contexte d'inhibition de bruit verbal ambiant permettrait également de reproduire un défi fréquemment rencontré dans la vraie vie, et donc d'améliorer la validité écologique de l'entraînement mnésique.

1.6. Objectifs et hypothèses de la recherche

L'objectif général de cette thèse est de tester si le fait d'enrichir un entraînement mnésique avec diverses conditions représentantes de la vraie vie est efficace chez des personnes âgées avec plainte mnésique (ou DCS), et de mesurer si ces conditions favorisent le transfert de contexte à l'aide d'outils à la fois objectifs et près du quotidien. L'un de ces outils sera précédemment construit à l'aide de la RV immersive, de même qu'évalué en termes de faisabilité et de validité.

1.6.1. Article 1. *La boutique virtuelle*, un environnement de réalité virtuelle immersive visant l'évaluation de la mémoire épisodique en situation quotidienne

Objectifs

Le but de l'article 1 est d'évaluer la faisabilité et la validité de La boutique virtuelle chez une population d'adultes jeunes et âgés. La boutique virtuelle est une nouvelle tâche de

RV immersive construite pour évaluer la mémoire épisodique dans un contexte plus écologique que celui proposé par les outils actuels.

Un premier objectif est de mesurer la faisabilité de la tâche, c'est-à-dire si les personnes jeunes et âgées sont en mesure de se déplacer en marchant dans l'environnement virtuel et d'utiliser le matériel pour sélectionner et valider des objets. Plusieurs paramètres tels que la variabilité des résultats et le temps de complétion seront également mesurés.

Un deuxième objectif est d'évaluer la validité de construit, c'est-à-dire si la tâche mesure effectivement la mémoire épisodique. Celle-ci sera d'abord mesurée via la méthode de différence de groupes (i.e., jeunes vs âgés), c'est-à-dire que les groupes seront comparés sur leurs scores de performance à la tâche de La boutique virtuelle. La validité de construit sera également évaluée via la méthode de validité convergente, en mesurant les liens entre la performance obtenue à La boutique virtuelle et celle obtenue à une mesure de mémoire épisodique classique. Comme il est supposé que la performance à La boutique virtuelle évalue la mémoire en contexte complexe où notamment l'inhibition est sollicitée, son lien avec une mesure classique d'inhibition sera étudié.

Un troisième objectif est d'évaluer la validité écologique de La boutique virtuelle, en étudiant ses liens avec un questionnaire auto-rapporté mesurant les difficultés mnésiques quotidiennes.

Afin de répondre à ces trois objectifs, deux études seront menées. Dans un premier temps, 20 jeunes adultes et 19 personnes âgées en santé compléteront La boutique virtuelle. Les groupes seront comparés sur le plan du nombre de bonnes réponses, le nombre d'erreurs, le nombre d'objets sélectionnés, le nombre d'objets validés, le temps d'initiation et le temps de compétition. Pour ce faire des tests-t à groupes indépendants seront réalisés. Une observation qualitative des scores et des réactions des participants sera aussi effectuée. Dans un deuxième temps, trente-cinq individus répondant aux critères d'un DCS compléteront La boutique virtuelle, une tâche de mémoire épisodique (*Épreuve de rappel libre / rappel indicé à 16 items,* RL/RI-16 ; Van der Linden et al., 2004), une tâche exécutive (*Stroop-Victoria* ; Moroni & Bayard, 2009), et un questionnaire d'auto-évaluation de la mémoire au quotidien (*Multifactorial Memory Questionnaire – Échelle de capacité,* MMQ-Ability ; Fort, Adoul, Holl, Kaddour, & Gana, 2004). À l'aide du MMQ, un score de capacité de mémoire spécifique aux tâches d'achats quotidiens sera aussi calculé (i.e., MMQ-Shopping). Les relations entre les scores aux différentes variables seront analysées par des corrélations de Pearson bi-variées.

Hypothèses

1) Il est attendu que La boutique virtuelle affiche une bonne faisabilité, tant chez les jeunes que chez les personnes âgées. Cette hypothèse sera mesurée de façon globale en prenant en compte un ensemble de facteurs qualitatifs et quantitatifs c'est-à-dire : que les participants seront en mesure de se déplacer de façon sécuritaire dans l'environnement; ils pourront utiliser le pointeur pour sélectionner des objets et en valider/annuler la sélection ; les scores de bonnes réponses afficheront une bonne variabilité et aucun effet plancher ou plafond ; et la tâche sera complétée dans un délai raisonnable.

2) Les jeunes adultes afficheront une performance supérieure à celle des personnes âgées à la tâche de La boutique virtuelle, appuyant la validité de construit de la tâche.

3) Une corrélation positive est attendue entre la performance à La boutique virtuelle et le score de rappel libre différé du RL/RI-16, appuyant la validité de construit de la tâche.

4) Une corrélation négative est attendue entre la performance à La boutique virtuelle et le score de plainte cognitive du MMQ-Shopping, appuyant la validité écologique de la tâche.

5) Les scores obtenus à La boutique virtuelle seront corrélés au score d'inhibition cognitive du Stroop-Victoria, puisque la tâche mnésique en RV comporte des stimuli visuels et auditifs distracteurs.

1.6.2. Article 2. Entraînement de la mémoire épisodique chez les personnes avec plainte mnésique : utilisation de la réalité virtuelle pour l'évaluation et la promotion du transfert

Objectifs

L'article 2 examine les effets de transfert de contexte d'un entraînement de la mémoire et si le fait d'enrichir un entraînement par des exercices en RV permet d'améliorer le transfert.

Précisément, l'étude vise à comparer si les effets de transfert sont mieux mis en évidence par des tâches en RV que par des mesures auto-rapportées. Elle a ensuite pour but de déterminer si un entraînement à la méthode des lieux enrichi d'exercices en RV immersive peut mener à des effets supérieurs de transfert de contexte, comparativement à un entraînement unique à la méthode des lieux. Ensuite, cette étude s'intéresse à savoir si les effets de transfert diffèrent selon la dose d'entraînement reçue, soit trois ou six séances d'intervention consécutives. Pour répondre à ces objectifs, 40 personnes âgées en santé avec plainte mnésique compléteront six séances d'entraînement à la méthode des lieux. Elles seront randomisées en deux conditions, soit avec (RV+) ou sans (RV-) exercices mnésiques effectués dans La boutique virtuelle. L'efficacité de l'intervention sera mesurée à l'aide d'une tâche de rappel libre de mots très proche de la tâche entraînée, variant uniquement en ce qui a trait à la modalité de présentation des mots (auditive vs visuelle). Le transfert de contexte sera évalué avec La boutique virtuelle, La promenade en voiture virtuelle, et l'échelle MMQ-Capacité (Fort, Adoul, Holl, Kaddour, & Gana, 2004). Les participants seront soumis à ces mesures avant l'intervention (PRÉ), après la troisième séance (POST 3) et après la sixième séance (POST 6) d'intervention. Seul le MMQ-Capacité sera complété seulement au PRE et au POST 6, ses passations ne pouvant être trop rapprochées. Des analyses mixtes de variance (ANOVA) seront utilisées afin d'examiner les effets de la condition d'intervention (RV+ ; RV-) et du moment d'évaluation (PRÉ ; POST 3 ; POST 6) sur les scores obtenus aux différentes mesures. Des corrélations de Pearson bi-variées serviront ensuite à analyser la relation entre les changements mesurés sur les différentes mesures de transfert et ceux observés sur la mesure d'efficacité de l'entraînement.

Hypothèses

1) Des effets de transfert sont attendus pour le groupe RV+ sur les deux mesures de transfert de contexte en RV, mais pas sur la mesure de transfert de contexte auto-rapportée.

2) Les participants du groupe RV+ montreront des effets de transfert de contexte supérieurs à ceux du groupe RV-. Précisément, le groupe RV+ montrera plus d'amélioration que le groupe RV- sur les mesures de transfert de contexte suite à l'intervention. Cette supériorité sera observée tant au POST 3 qu'au POST 6.

3) Les participants auront une amélioration graduelle de leur performance tant pour la mesure d'efficacité de l'intervention que sur celles de transfert de contexte, c'est-à-dire que la performance au POST 3 sera supérieure à celle en PRÉ, et que la performance au POST 6 sera supérieure à celle en POST 3.

1.6.3. Article 3. Entraînement de la mémoire en situation de bruit ambiant chez les personnes avec plainte mnésique

Objectifs

L'article 3 vise à évaluer l'efficacité d'un entraînement d'inhibition auditive et si l'entraînement auditif peut amplifier l'efficacité et le transfert d'un entraînement mnésique classique concurrent. Le but est de déterminer si un entraînement à la méthode des lieux peut améliorer la mémorisation en contexte bruyant, et si le fait de coupler cet entraînement mnésique à un entraînement visant l'inhibition auditive peut augmenter cet effet. Afin d'atteindre cet objectif, 40 personnes âgées en santé avec plainte mnésique compléteront six séances d'entraînement à la méthode des lieux. Ils seront randomisés en deux conditions, soit avec (MÉMOIRE+ATTENTION) ou sans (MÉMOIRE+MÉMOIRE) exercices mnésiques effectués en contexte de bruit verbal ambiant. Les trois premières séances se dérouleront de façon identique dans les deux conditions et seront dédiées à l'apprentissage de la méthode des lieux. Dans les séances quatre à six, les participants du groupe MÉMOIRE+ATTENTION compléteront des exercices de mémoire avec la méthode, mais dans un contexte d'entraînement de l'inhibition cognitive. Chaque exercice sera réalisé dans du bruit verbal ambiant dont le niveau de distractibilité augmentera graduellement, d'après le rendement de mémoire individuel. Le groupe MÉMOIRE+MÉMOIRE complétera pour sa part les exercices en silence. Les effets de l'intervention seront mesurés grâce à deux tâches de rappel de 12 mots, l'une effectuée dans un environnement silencieux, l'autre effectuée en contexte de bruit verbal. Ces tâches seront complétées à trois reprises, soit avant l'intervention (PRÉ 1), suite à la troisième séance (PRÉ 2) et après à l'intervention (POST). Le PRÉ 2 permettra de bien isoler les effets des deux conditions d'entraînement (présentes dans les séances quatre à six), puisque les séances une à trois sont identiques pour tous. Des ANOVA mixtes seront utilisées afin d'examiner les effets de la condition d'intervention (MÉMOIRE+ATTENTION ;

MÉMOIRE+MÉMOIRE) du moment d'évaluation (PRÉ 1 ; PRÉ 2 ; POST), et du contexte auditif de la tâche (silence ; bruit) sur les scores obtenus aux deux tâches de rappel.

Hypothèses

1) Les deux groupes auront une meilleure performance à la tâche de rappel de mots suite à l'apprentissage de la méthode des lieux (du PRÉ au POST 1).

2) Après avoir reçu l'entraînement attentionnel (du PRÉ 2 au POST), le groupe MÉMOIRE+ATTENTION montrera une réduction plus importante de l'effet délétère du bruit sur la mémoire, comparativement au groupe MÉMOIRE+MÉMOIRE.

Chapitre II

Article 1

Article 1

The Virtual Shop: A new immersive virtual reality environment and scenario for the assessment of everyday memory

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Abstract

Background

Assessing and predicting memory performance in everyday life is a common assignment for neuropsychologists. However, most traditional neuropsychological tasks are not conceived to capture everyday memory performance.

New Method

The Virtual Shop is a fully immersive task developed to assess memory in a more ecological way than traditional neuropsychological assessments. Two studies were undertaken to assess the feasibility of the Virtual Shop and to appraise its ecological and construct validity. In study 1, 20 younger and 19 older adults completed the Virtual Shop task to evaluate its level of difficulty and the way the participants interacted with the VR material. The construct validity was examined with the contrasted-group method, by comparing the performance of younger and older adults. In study 2, 35 individuals with subjective cognitive decline completed the Virtual Shop task. Performance was correlated with an existing questionnaire evaluating everyday memory in order to appraise its ecological validity. To add further support to its construct validity, performance was correlated with traditional episodic memory and executive tasks.

Results

All participants successfully completed the Virtual Shop. The task had an appropriate level of difficulty that helped differentiate younger and older adults, supporting the feasibility and construct validity of the task.

Comparison with Existing Method(s)

The performance on the Virtual Shop was significantly and moderately correlated with the performance on the questionnaire and on the traditional memory and executive tasks.

Conclusions

Results support the feasibility and both the ecological and construct validity of the Virtual Shop.

Keywords: virtual reality, virtual environment, memory, neuropsychological assessment, aging.

1. Introduction

Appraising memory difficulties and their impact on everyday life is critical, as a large number of diseases impair memory capacities. However, traditional neuropsychological tasks are designed to obtain the person's best performance in optimal conditions and hence poorly capture everyday memory deficiencies. Real life situations that involve memory are generally more complex than traditional memory tasks, as they are most often done under multitasking and distracting conditions or while the person is in movement. Furthermore, traditional tests bear little resemblance to common, everyday memory situations. As a result, the relationship between performance on traditional memory tests (e.g., CVLT or WMS-R scales, etc.) and measures of everyday functioning (e.g., self and informant memory diary, patient and informant memory questionnaire, clinical rating, etc.) are at best moderate (see Chaytor & Schmitter-Edgecombe, 2003, for a review; Goldstein et al.,1992; Johnson, 1994; Kaitaro et al.,1995; Makatura et al., 1999; Sunderland et al., 1983), and sometimes absent (Higginson et al., 2000).

The use of virtual reality (VR) can provide a solution to evaluate memory in ecologically relevant and standardized conditions. VR is a computer-based technology that allows users to interact with a three-dimensional multisensory simulated environment (Saposnik & Levin, 2011). The technology is interesting for cognitive assessment because of its capacity to simulate naturalistic environments (Rizzo et al., 2004) while generating safe experimental conditions that are replicable and that remain entirely under the experimenter's control.

A number of studies support the construct validity of VR protocols, i.e., their ability to measure the intended concept (O'Leary-Kelly & Vokurka, 1998). First, many studies have reported positive correlations between performance on VR tasks and traditional or neuropsychological measures targeting the same cognitive functions (Matheis et al., 2007; Lalonde et al., 2013; Henry, Joyal, & Nolin, 2012; Armstrong et al., 2013; Nolin et al., 2016). Second, it has been shown that several VR tests can differentiate between two groups known to perform at different levels on tasks, such as healthy vs. demented older adults (Allain et al., 2014; Banville et al., 2010; Tarnanas et al., 2013; Rand et al., 2007; Werner et al., 2009; Zygouris et al., 2014; Plancher et al., 2012, Rizzo et al., 1997; Rizzo et al., 2001; Cushman, Stein & Duffy, 2008; Tarnanas et al., 2015). Furthermore, several studies have shown that VR assessments have ecological validity, i.e., they are able to predict everyday performance (Franzen & Wilhelm, 1996). This was measured by comparing the performance in VR tasks with the performance in equivalent real life tasks (Waller, Knapp, & Hunt, 2001; Cushman, Stein & Duffy, 2008; Allain et al., 2014; Renison et al., 2012; Vallejo et al., 2017) or with self-rated questionnaires of daily functioning (Potvin et al., 2011; Plancher, Gyselinck, Nicolas, & Piolino, 2010; Tarnanas et al., 2013). For instance, in the spatial domain, high correlations were found between spatial learning measured with a virtual maze and a similar real-world maze (Waller et al., 2001) and between spatial navigation measured with a virtual vs. a real hospital lobby (Cushman et al., 2008). In the executive domain, performance on different tasks associated with the day-to-day running of a virtual library was correlated with performance on real life analogous tasks performed in a real library where participants interacted with real objects (Renison et al., 2012). Similarly, the capacity to prepare a cup of coffee (Allain et al., 2014) or to perform a cooking task (Vallejo et al., 2017) in virtual contexts predicted the capacity to perform similar tasks in a real-world setting.

However, most studies on VR assessments have focused on attention (Rizzo et al., 2001; Nolin et al., 2016), executive functions (Lalonde et al., 2013; Armstrong et al., 2013; Henry, Joyal, & Nolin, 2012; Banville et al., 2010; Cipresso et al., 2014), or spatial learning and navigation (Aguirre & D'Esposito, 1997; Gould et al., 2007; Weniger & Irle, 2008; Weniger et al., 2009; Weniger et al., 2011; Iglòi et al., 2009; Moffat, Zonderman & Resnick, 2001; Head & Isom, 2010; Weniger et al., 2010; Siemerkus et al., 2012). There are surprisingly few virtual environments or scenarios that have been validated to assess memory activities, and those that have been have mostly relied on object or associative memory (Sauzéon et al., 2012; Sauzéon et al., 2016a; Sauzéon et al., 2016b; Matheis et al., 2007; Plancher et al., 2010; Plancher et al., 2012; Jebara et al., 2014). There are no or very few VR tests that have been conceived to assess memory in the context of typical activities of daily living such as cooking or shopping. Furthermore, the majority of VR studies interested in memory have not relied on *immersive* virtual reality (IVR). In IVR systems, the user wears a display that produces a fully immersive experience and in which computer-generated stimuli evoke multiple senses (i.e., vision, hearing, etc.) (Biocca & Delaney, 1995). IVR requires a stereoscopic head-mounted display (HDM) that optimizes the immersion of the participants inside the virtual environment by allowing a complete 360-degree view. This increases the realism of the virtual scene and the user's impression to genuinely take part in the environment, a characteristic, which is referred to as the *sense of presence* (Witmer & Singer, 1998). Currently, most VR memory assessments present their environment on a flat-screen (Weniger & Irle, 2008; Weniger et al., 2009; Weniger et al., 2011; Iglòi et al., 2009; Moffat, Zonderman, & Resnick, 2001; Head & Isom, 2010; Weniger et al., 2010; Siemerkus et al., 2012; Sauzéon et al., 2012; Sauzéon et al., 2016a; Sauzéon et al., 2016b) or on a semi-circular screen (Plancher et al., 2010; Plancher et al., 2012; Jebara et al., 2014), and are therefore non-immersive. The resemblance with a real-world task is further limited by the use of artificial navigation modes such as game pad devices (Parsons & Rizzo, 2008) or the absence of navigation (Matheis et al., 2007). It has been shown that sense of presence is higher for natural navigation mode, such as real walking, than for virtual walking or navigation via pushing a button (Usoh et al., 1999). To our knowledge, the issues of basic feasibility of IVR coupled with a natural navigation mode such as real walking have never been addressed in the field of cognitive assessment.

Thus, VR technologies have considerable potential to assess memory difficulties in everyday life, beyond that of current neuropsychological measures. However, the realism of the current VR tools should be upgraded with more common day-to-day scenarios and the utilization of IVR and a naturalistic navigation mode. This should support the development of IVR assessments that have a better construct and ecological validity to optimize the prediction of everyday memory performance.

The overall objective of this study was to develop an ecologically-valid VR environment and scenario, designed to measure everyday memory in older adults while addressing the limits described above. This new test, the Virtual Shop, was devised with IVR, using natural navigation mode (i.e., walking) and simulating a meaningful and common day-to-day situation: shopping for common items in a convenience store. The task consists in memorizing a shopping list of common items and then to find and fetch them at a convenience store. The first objective was to determine the feasibility of this new VR task in younger and older individuals (Study 1). The task was expected to show good feasibility that is, younger and older adults were expected to be able to walk in the environment, select objects, and use the remote options to validate and cancel object selections. We anticipated that the VR task would have an appropriate difficulty level, with no floor or ceiling effects in terms of correct selections, and that all participants would complete the VR task in a relatively short period of time. A second objective was to assess its ecological validity by measuring the relationship between performance on the VR task and responses on a questionnaire measuring difficulties related to shopping in older individuals with a memory complaint (Study 2). It was expected that performance on the VR task would correlate with the capacity to perform shopping tasks in real life as measured by the questionnaire. A third objective was to measure construct validity. This was done using the contrasted-group method by assessing the effect of aging on VR memory performance in Study 1 and by measuring the relationship between performance on the VR task and performance on a traditional memory tests and on a test that reflects executive functions and processing speed in Study 2. VR task performance was expected to be sensitive to age differences, i.e., younger adults would perform better than older ones. Furthermore, VR task performance was expected to correlate with performance on a traditional episodic memory task. Since the VR task is complex and involves interference, it was also expected that the Virtual Shop task would correlate, albeit to a lower level, with performance on a traditional measure of executive functions.

2. STUDY 1: Feasibility and construct validity with the contrasted-group method

To determine the feasibility of the Virtual Shop, study 1 examined whether participants had appropriate interactions with the interfaces of the IVR system and whether the Virtual Shop task had suitable levels of difficulty. The study also addressed construct validity by contrasting the performance of older and younger adults. Because age is associated with a decline in episodic memory (Park et al., 2002), it was expected that older adults would perform worse than younger adults on the Virtual Shop task.

2.1. Material and method

2.1.1. Participants

Forty-nine participants (20 younger adults and 19 older adults) were recruited through postings, magazines for seniors and the CRIUGM participant registry (*Banque de participants du CRIUGM*). Participants were French-speaking, had normal or corrected-to-normal vision, normal hearing and were cognitively healthy (score ≥ 26) according to the Montreal cognitive assessment (MoCA; Nasreddine et al., 2005). Among the younger adults 13 were female and 7 male. They had a mean age of 21.65 years (*SD* = 2.46) and a mean education level of 10.55 years (*SD* = 2.05). The older adults comprised 15 females and 4 males with a mean age of 68 years (*SD* = 5.03) and a mean education level of 9.63 years (*SD* = 3.56). Group comparisons using *t*-tests and chi-square for gender comparison revealed no significant differences on demographic characteristics.

2.1.2. IVR measure of everyday memory: The Virtual Shop

The Virtual Shop (in French; *La boutique virtuelle*) is a virtual convenience store that includes the scenario of a shopping task designed to assess everyday memory. The VE is three dimensional, fully immersive and includes the following interactions: navigation (via natural walking), item selection (via a pointer) and a conversation with a character (via natural talking).

2.1.2.1. Virtual environment. The Virtual Shop (see figure 1) was developed in collaboration with the Cliniques et Développement In Virtuo (http://www.cliniqueinvirtuo.com). The environment measures approximately 3.5 X 6.5 m. and contains common shop elements. Its configuration comprises two central shelves and three refrigerators. A long countertop is placed in the right superior corner and there is a television behind it, which broadcasts a soccer match. Different characters are present in the environment: a cashier sitting behind the countertop and two customers standing in the right inferior corner of the shop (see figure 1). The Virtual Shop is run by the program *Virtools 5* on a Dell Precision T3600 PC with an Inter(R) Xeon (R) CPU ES-1620 0 (3.60 Ghz, 10 Gbytes in RAM) processor and a NVIDIA GeForce GTX 600 Ti graphic card. Three-dimensional visual images are presented using the HMD *nVisor ST50*. The HMD provides a stereoscopic vision via two screens placed in front of the eyes (1280 x 1024 full color with 50° diagonal field-of-view) and sound by stereo headphones. The HMD is connected to a PPT-X system (6 degrees of freedom) motion tracker by *WorldViz* which transmits head position/rotation to a *Shuttle* PC computer in order to provide real-time updating of the VE. It allows the user to rotate his/her head in a 360-degree view and to walk freely in the VE. A motion tracker is also attached to the participant's right hand. The participant moves his or her hand to position a red circle on the objects they want to select. A wireless remote held in the subject's right hand allows the participant to complete the selection of the item by pressing a button. To avoid errors by accidentally pressing the button, the participant is asked to confirm the selection by pressing a validation button. The virtual store is programmed to fit the dimensions of the experimental room in which the task takes place.

Figure 1. The Virtual Shop

Figure 1. The image shows a version of the Virtual Shop with the items placed on shelves and hung on the walls. In the background, there is the countertop with the cashier.

2.1.2.2. Virtual objects. Seventy-two objects were created to fill the Virtual Shop as targets or distractors (note that these objects could be used in any other virtual environment). Different variables were controlled, tested and reviewed during their development to ensure the objects are equivalent and unambiguous. We first identified 12 semantic categories from each of which six items were identified (Marchal & Nicolas, 2003). They were all concrete objects commonly found in small shops. Each item was then designed in 3D by a professional digital designer to resemble real products. We then used an adaptive/agile procedure to validate the naming of objects, based on previous studies that have validated a set of pictures (Snodgrass & Vanderwart, 1980; Sirois et al., 2006; Brodeur et al., 2014). Effectively, drawings can be misinterpreted and using unambiguous stimuli is crucial in psychological assessments so as to ensure the limitation of confounding variables (e.g., encoding the object with correct/incorrect semantic information). In a first iteration, younger adults were first asked to name the 72 objects. This was done by presenting the 3D virtual objects in a 2D representation of the drawn object one by one on a 15-inch black screen of a PC computer. Items remained on the screen until a response was produced. Naming was judged as correct if it represented the name previously determined for the concept or was a synonym on the basis of the experimenters' judgment. Eight objects were incorrectly identified (less than 60% of correct naming: leek, celery, nightlight, duster, nails, sponge, fork, secateurs)[1]. In the second iteration, drawings that had been incorrectly named were modified. Older adults were then showed the improved images one by one on a 15-inch screen of a PC computer and were asked to name them. Twelve objects were incorrectly identified (grape, grapefruit, kiwi, beer, wine, cap, nightlight, pencil sharpener, sponge, secateurs, rake). These objects were modified again and their improved versions were validated liberally by our research team.

2.1.2.3. Scenario of the everyday memory task. Prior to completing the memory VR task, participants were familiarized with the virtual devices using a different version of the convenience store in a condition where they were simply asked to walk in the environment and to select an item that was not used in the memory test. They were then introduced to the episodic memory task. The participant was first positioned in front of the countertop, with the

[1] Three drawings were not used on the first iteration due to technical or 3D designed problems.

shop shelves behind him/her. The experimenter explained to the participant that s/he would be presented with a list of items to memorize and that s/he would later have to ‘‘buy’’ these same items. The experimenter explained that the cashier of the shop will ask two questions the participant will have to answer and will then be instructed to start shopping. The pictures of 12 items were then presented on the flipping pages of a notepad situated on the countertop. A picture of an object was presented in the center of each page with its name written below to ensure that products were correctly identified. Objects were presented one after the other at a rate of one item every 5 seconds. When presentation was over, the cashier asked the participant a set of brief questions (e.g., ‘‘What is the weather like today?’’) during 20 seconds as a way to empty the content of the participant’s working memory. The cashier then instructed the participant to walk into the store and fetch the objects that had been shown on the pad (‘‘Thanks, you can now go shopping’’). The objects were located on shelves, inside refrigerators, hung on walls, or were placed on the floor**.** Positions were randomized although they were in their appropriate location (e.g., the milk was placed in the refrigerator). Twelve distractors that belonged to the same semantic category as the target items were placed in similar locations. Ambient verbal noise – a conversation between two customers – was presented dichotically through the HMD during the whole task. This was done to increase the ecological validity of the task by reproducing a task completed under distracting conditions.

The following measures were recorded during completion of the VR task: initiation time (time before the beginning of the task and the selection of the first object), time to complete the task, total number of selected objects (validated and non-validated), number of validated objects, number of correct responses, and number of errors (intrusions and repetitions).

2.2. Results

Table 1 displays the parameter values that were recorded in the Virtual Shop task.

Table 1

Performance in the Virtual Shop

	Younger adults $N = 20$		Older adults $N = 19$	
Measure	Range	Mean (SD)	Range	Mean (SD)
Correct responses (/12)	5-12	9.60 (1.97) *	2-12	7.68 (2.73)
Errors (intrusions + repetitions)	0-1	0.10 (0.31)	0-2	0.16 (0.50)
Selected objects	5-17	10.55 (2.54)	5-18	9.63 (4.19)
Validated objects	5-12	9.70 (1.92) *	4-12	8.00 (2.36)
Initiation time (s)	1-72	24.25 (19.33) *	87-104	38.68 (24.51)
Total time (s)	210-643	312.65 (99.17) *	300-782	487.74 (158.08)

**Significant group difference; p < .05*

2.2.1. Feasibility. Correct responses ranged from 5 to 12 in younger adults and from 2 to 12 in older adults. Only 4 younger and 2 older adults reached the maximum performance. We found no evidence of a floor or ceiling effect in either group and the task yielded a variability of scores. The number of errors was negligible. In both groups, participants selected more objects than they validated. Younger adults validated 93% (mean score) of their selected objects and older adults 87% of them. The initiation time ranged from 1 to 104 seconds and the completion time ranged from 210 to 782 seconds. Finally, it is important to mention that the IVR system was generally well tolerated, with no case of task discontinuation due to cybersickness symptoms (see also Corriveau-Lecavalier, Ouellet, Boller, & Belleville, 2018).

2.2.2. Validity. Separate independent sample *t*-tests were conducted to test group differences on each of the parameter values recorded in the Virtual Shop. Relative to younger adults, older adults reported less correct responses, [$t(37) = 2.44$, $p < .05$; $d = 0.81$], were slower to initiate their first selection [$t(37) = -2.16$, $p < .05$; $d = 0.65$], and required more time to complete the task [$t(37) = -3.88$, $p < .01$; $d = 1.33$]. The groups did not differ in their number of errors [$t(37) = -0.49$ $p = .63$] and in the ratio selected over validated objects [$t(37) = 1.37$, $p = .18$].

3. STUDY 2: Ecological validity and construct validity with correlations between performance on the Virtual Shop, an everyday memory questionnaire and traditional memory tests

One objective was to appraise the ecological validity of the VR memory task by assessing whether performance on the Virtual Shop task was related to memory performance in real-life shopping activities as measured with a self-rated questionnaire. Another goal was to appraise the construct validity of the VR memory task by assessing whether performance in the Virtual Shop task was correlated with memory performance on a traditional memory task. Recall in the Virtual Shop task is not immediate as participants need to navigate in the environment to fetch the objects and as shown in Study 1, completion time ranged from about 5 to 13 minutes. Thus, the score was compared with delayed recall. This was assessed in older individuals with subjective cognitive decline (SCD). Persons with SCD perform normally for their age on classical memory tests but express a concern about their everyday memory capacities (Jessen et al., 2014). Thus, this group was likely to produce sufficient variability in their level of complaint to assess the relationship between this score and VR performance. A negative correlation was expected between performance on the VR memory task and the level of complaint regarding shopping and errands as a support for ecological validity. A positive correlation was also expected to be found between the performance on the VR memory task and performance on a traditional measure of episodic memory as a further support for construct validity.

3.1. Material and method

3.1.1. Participants

Thirty-five older adults with SCD were recruited through postings, magazines for seniors and the CRIUGM *Banque de participants*. Participants were French-speaking, had normal or corrected-to-normal vision and normal hearing. Participants were included if they met the Jessen et al. (2014) criteria for SCD group. First, they answered ‘‘yes’’ to the two following questions: ‘‘Do you feel like your memory is becoming worse?’’ and ‘‘Does it worry you?’’ Second, they showed no impairment on objective measures of cognition based on the Story Recall II Part A of the Wechsler Memory Scale-III (Wechsler,1997; Québec

French adaptation), the MoCA (Nasreddine et al., 2005) and the Stroop-Victoria test (Troyer, Leach, & Strauss, 2006; French adaptation from Moroni & Bayard, 2009; Québec French norms from Tremblay et al., 2016. Performance on the Stroop (completion time) was deemed normal when scores were no longer than 1.5 standard deviations away from the mean of age- and education- matched normative samples. Performance on the Story Recall task was considered normal based on education-adjusted cut-off scores used in the ADNI (Alzheimer's Disease Neuroimaging Initiative) study and taken from Bennett et al. (2002) and Petersen et al. (2010). Performance on the MoCA was considered normal if it was equal or higher than the 26 cut-off score, as determined by Nasreddine et al. (2005) (see Table 2). Participants included 29 females and 6 males with a mean age and of 67.20 years (*SD* = 7.87) and a mean education level of 16.06 years (*SD* = 3.02).

Table 2

Clinical characterization

Measure	Score Mean (SD)	Cut-offs for normal score
Stroop Victoria (*Z* score for time)		
First plate	0.13 (0.66)	≤ 1.50
Second plate	0.07 (0.56)	≤ 1.50
Third plate	0.05 (0.66)	≤ 1.50
MoCA (/30)	27.74 (1.65)	≥ 26
Logical Memory IIA, WMS-III (/25)	15.51 (3.57)	8 years of education: > 3
		9-16 years of education: > 5
		> 16 years of education: > 9

Note. MoCA = Montréal Cognitive Assessment; WMS = Wechsler Memory Scale.
Note. A negative *Z* score for the Stroop means a better performance score than what is normally expected.

3.1.2. Instruments

All participants completed the *Multifactorial Memory Questionnaire* (MMQ – memory ability scale [MMQ-ability], Troyer & Rich, 2002; French version: Fort, Adoul, Holl, Kaddour, & Gana, 2004), which measures memory in everyday life (internal consistency measured by Cronbach's alpha = .88). Participants were asked to rate difficulties in performing different daily memory activities on a Likert scale ranging from 1 (*never*) to 5 (*all the time*). Thus, a larger score indicates more frequent difficulties with the activity. Here, we focused on two questions that refer to shopping activities (item 8: *How often do you forget to run an errand?* and item 19: *How often do you forget to buy something you intended to buy?*). The scores of the two questions were added up to obtain a single score (MMQ-shopping). Participants also completed a validated neuropsychological measure of verbal episodic memory (*Épreuve de rappel libre / rappel indicé à 16 items,* RL/RI-16; Van der Linden et al., 2004), which involves word-list learning with immediate and delayed free and cued recall. The delayed free recall was selected for this study, as it is more comparable to the VR retrieval measure than the immediate free recall, given that both have a delay between encoding and recall. The Stroop-Victoria (Troyer, Leach, & Strauss, 2006; French adaptation from Moroni & Bayard, 2009) was used as a measure of executive functions. In this task, participants must name the stimuli presented on a plate as fast as possible under three conditions: 1) naming the color of the ink of colored dots (dots printed in blue, green, yellow or red); 2) naming the color of the ink of common words printed in the same colors as dots; 3) naming the color of the ink of color words printed in a conflicting color (e.g., the word blue printed in red). Thus, the third condition requires participants to suppress a habitual or automatic response in favor of another. The completion time and number of errors were measured for each condition, but here we only used completion time as a measure of performance because of the lack of variability across participants in the number of errors. Two scores were computed using completion time: 1) Word/Dot (low interference) and 2) Interference/Dot (high interference). Finally, the Virtual Shop task was completed as described above (cf. study 1). The questionnaire and the neuropsychological assessment were completed in a single session prior to the one where they completed the Virtual Shop task.

3.2. Results

Table 3 displays the scores from the Virtual Shop, the MMQ-shopping and the RL/RI-16. A Pearson correlation analysis showed that the number of correct answers in the Virtual

Shop was negatively correlated with the MMQ-shopping complaint score ($r = -0.34$, $p < .05$). Thus, lower recall in the Virtual Shop task was associated with reporting more frequent difficulties related to shopping in daily life. The initiation time score of the Virtual Shop was also correlated with the MMQ-shopping complaint score ($r = 0.42$, $p < .05$); participants who took more time to select the first item in the Virtual Shop task also showed a higher MMQ-shopping complaint score. There was no association between time to complete the VR task ($r = -0.06$, $p = .75$) and the MMQ-shopping complaint score. Importantly, performance on the Virtual Shop was not correlated with the global MMQ-ability score ($M = 45.82$, $SD = 12.39$; correlation with correct recalls: $p = .44$) or with the MMQ-ability score that pulled out the 2 shopping items (correlation with correct recalls: $p = .13$). This indicates that the relationship between the RV task and performance in daily life is specific to activities similar to those tested in the Virtual Shop.

The scores for correct recall in the Virtual Shop task were positively correlated with traditional neuropsychological measure of episodic memory ($r = 0.35$, $p < .05$). However, performance on the measure of episodic memory did not correlate with the MMQ-shopping complaint score ($p = .10$), the global MMQ-ability score ($p = .29$) or with the MMQ-ability score when the 2 shopping items were removed ($p = .53$).

Initiation time on the Virtual Shop was positively correlated with completion time for the first ($r = 0.40$, $p < .05$), second ($r = 0.62$, $p < .01$), and third plate ($r = 0.52$, $p < .01$) of the Stroop-Victoria. A similar effect was found for correct recall on the Virtual Shop task, which was negatively correlated with the completion time for the first ($r = -0.52$, $p < .01$), second ($r = -0.49$, $p < .01$), and third plate ($r = -0.53$, $p < .01$) of the Stroop-Victoria. The MMQ-shopping complaint score ($r = 0.59$, $p < .01$) was positively correlated with completion time on the third plate. The low and high interference scores were not correlated with any of the VR scores.

Table 3

Performance on the Virtual shop, subjective memory questionnaire and neuropsychological measures

Measure	Raw score Mean (SD)
The Virtual Shop	
Correct responses (/12)	7.23 (2.78)
Initiation time (s)	32.66 (30.75)
Total time (s)	479.46 (152.90)
MMQ-Shopping (/8)	4.86 (1.42)
RL/RI-16 delayed free recall (/16)	12.03 (1.77)
Stroop Victoria	
Low interference score	1.29 (0.16)
High interference score	2.17 (0.51)

Note. MMQ-Shopping = a single score which comes from the addition of the two questions related to shopping in the Multifactorial Memory Questionnaire - Memory Ability Scale; RL/RI-16 = 16-item Free and Cued Recall.

4. Discussion

The Virtual Shop task is a fully immersive VR task designed to assess everyday memory. Our main goal was to assess its feasibility in younger and older adults and to assess its construct validity by contrasting the performance of younger and older adults on the task (cf. study 1) and by correlating VR scores with scores on a traditional measure of episodic memory (cf. study 2). We also wanted to provide preliminary ecological validity data by correlating the performance on the Virtual Shop to memory performance in shopping activities (cf. study 2). Overall, results suggest that the Virtual Shop is an adequate and valid measure of everyday life memory in healthy individuals.

Our first objective was to assess the feasibility of the Virtual Shop task to measure everyday memory in younger and older adults. We examined how the two age groups behaved and performed during the scenario of the Virtual Shop. We were interested in the distribution of scores and completion time and how they interacted with virtual objects. We found that younger and older adults were able to perform the task and that there was neither a floor, nor a ceiling effect, as only a few participants reached the maximal score. We also found that the overall completion time of the VR task was relatively short (less than 15 minutes for all participants) despite the fact that there was no time limit in the VR task and that the participant could explore the environment freely. This duration is close to the administration time of most episodic memory tests, which is an advantage as time is often limited in clinical or experimental cognitive assessment (Strauss, Sherman, & Spreen, 2006). Importantly, such a relatively short VR exposure time might help to minimize risks of cybersickness that can occur in immersive VR (Jaeger & Mourant, 2001).

We were also interested in the usability of the virtual pointer technique used to interact with the virtual objects, particularly for older adults. Typically, virtual pointer techniques are challenging because one needs to disambiguate the object where the user is pointing (Poupyrev et al. 1998). To avoid this problem, a validation step was added so that the user could cancel a selection when it was not the one they had intended to select. Younger adults cancelled 7% of their selections, whereas older adults cancelled 13% of them, and the difference was not significant between groups. This indicates that both groups used the validation procedure to cancel a selection and that it was appropriate to implement a two-step response strategy (select then validate) in the VR task, regardless of the participant's age. Thus, the procedure is an advantage, as it provides some flexibility for the user to select their response, and participants evidently do use it. The high level of performance in terms of correct answers suggests that object selection was not an obstacle in the success of the task. Nevertheless, some evidence shows that the manipulation of the virtual pointer is more challenging for older adults than for younger adults: the former group cancelled more responses and took more time than younger adults to initiate their first selection. This is consistent with previous findings indicating that mouse and touchscreen control is more difficult for older adults compared to younger adults (Smith, Sharit, & Czaja, 1999; Rogers et al., 2005; Findlater et al., 2013) and should be taken into account when these two groups are compared. Importantly, we found no evidence of difficulties regarding the navigation via real walking. This is important because the task involves a relatively cumbersome/heavy device to project the VR environment. One might have expected older adults to show balance problems or discomfort. However, this was not the case here, all participants fully completed the VR task and there was no incident in relation to the walking activity. The feasibility of walking navigation in VR assessment is therefore supported by our study. Nevertheless, our study highlights a few methodological issues that might be of relevance to those interested in designing a walking VR tasks for older adults. First, the longer completion time of older adults compared to younger ones could reflect not only age-related differences in cognitive performance but also age differences regarding walking speed. Thus, the time variable should be used with caution when comparing the memory performance of different age groups, because it might reflect more than just cognitive process. Furthermore, slower walking might slightly increase the delay between encoding and retrieval in older adults, a variable that might impact performance. On the other hand, walking while shopping is akin to reality. In real life, it is known that older adults have lower gait speed (Lajoie et al., 1996), that gait and cognition are strongly related (Ambrose et al. 2010; IJmker & Lamoth, 2012; Martin et al., 2013), and that older adults show gait changes when they simultaneously perform an attention-demanding task (Woollacott & Shumway-Cook, 2002; Beauchet et al., 2005). Thus, this is reflected in ecologically valid tasks such as the VR shopping task.

Our results from Study 1 and 2 support the construct validity of the Virtual Shop task. It was first evidenced by the contrasted groups approach of Study 1. In this approach, the mean score of two groups known to be high and low in the construct are compared and should differ significantly in the expected direction if the instrument is valid (Cronbach & Meelh, 1955; DeVon et al., 2007). As expected given appropriate construct validity, older adults showed a smaller number of correct recall and longer completion time than younger adults, which suggests that the VR task is sensitive to the aged-related difference in episodic memory. In addition, Study 2 showed that the performance of participants in the Virtual Shop task was positively correlated with the performance measured on a traditional neuropsychological measure of episodic memory. This suggests that the Virtual Shop task assesses a construct that is similar to the one measured by typical episodic memory tests. Overall, these results are consistent with those obtained in other studies, demonstrating the capacity of virtual assessments to measure specific cognitive functions (Plancher, Nicolas, & Piolino, 2008;

Plancher et al., 2012; Armstrong et al., 2012; Henry et al., 2012; Parsons & Courtney, 2014; Nolin et al., 2016) and to discriminate between populations (Gould et al., 2007; Tarnanas et al., 2013; Zygouris et al., 2014) including younger vs. older adults (Rand et al., 2007; Plancher et al., 2010; Cushman, Stein, & Duffy, 2008; Jebara et al., 2014). It is however important to point that though significant, the magnitude of the correlation between the Virtual Shop and the traditional episodic task is relatively weak, suggesting that other cognitive functions are involved in the Virtual Shop tasks.

Interestingly, Study 2 showed that completion time on the three Stroop-Victoria conditions shows a positive correlation with the time to select the first object (initiation time) in the Virtual Shop and a negative correlation with overall performance. We found no correlation between the VR task and interference scores. This suggests that the performance on the Virtual Shop task is linked to processing speed and not to executive function as measured here. The finding of a correlation between performance in the Virtual Shop and speed is not unexpected as episodic memory performance in aging has often been found to be mediated by processing speed (Bryan & Luszcz, 1996; Park et al., 1996; Hertzog, Dixon, Hultsch, & MacDonald, 2003). The absence of a contribution from inhibition processes is unexpected since the Virtual Shop task requires that participants inhibit auditory and visual interference. Lack of a correlation might be due to the fact that we are using only one inhibition task, which might not capture all of the processes involved in inhibition. It is also possible that our scenario was not sufficiently demanding on executive functions. Other virtual reality tasks were shown to correlate with executive measures (Raspelli et al., 2012; Cipresso et al., 2014), but those tasks were designed to solicit executive capacities. For instance, the VMET (The Virtual Multiple Errands Test, Raspelli et al., 2012), which involves 4 shopping tasks to be performed while respecting pre-determined rules, was found to highly correlate with performance on tests of divided attention, intermodal comparison, incompatibility and attention shift. Cipresso et al. (2014) also showed that the VMET better detects early executive deficits in Parkinson’s disease than traditional executive tasks.

Our findings suggest that the Virtual Shop is related to self-reported everyday performance in shopping, hence supporting its ecological validity. This was done by measuring the correlation between performance in the Virtual Shop and subjective complaint regarding shopping and running errands in persons with SCD. Importantly, the two measures were taken in separate sessions and they are thus unlikely to be influenced by spillover effects. Interestingly, the Virtual Shop was correlated with the MMQ-shopping – a score provided by the two questions related to shopping activities – but not to the global score of the memory questionnaire. This indicates that the memory performance measured in the Virtual Shop reflects the specific everyday memory performance in everyday shopping activities. Hence, it suggests that everyday memory is not a global concept but is highly related to the context of measurement.

Interestingly, we found no correlation between the self-rated MMQ-shopping and performance on the traditional episodic memory task. This is unsurprising because a number of studies have highlighted that traditional measures lack ecological validity (e.g., Higginson et al., 2000). Combined with the data reported above, this suggests that virtual assessment might be more sensitive to the memory complaints of older adults than traditional neuropsychological tests (Plancher et al., 2008; Plancher et al., 2010; Plancher et al., 2012), and might thus better reflect real-world performance (see Parsons et al., 2015, for a review). However, we found that the effect was quite specific in that the virtual shopping test was related to shopping activities but not to a global measure of memory. It seems that virtual assessments have the potential to measure memory, but that they may capture performance related to the very particular context reproduced by the VR environment and scenario.

These findings should be interpreted in the context of some limitations. First, other functions may be involved in the Virtual Shop task. Motor functions might be particularly relevant, as the VR task requires participants to walk in the environment and select items with a pointing device that requires manual dexterity. We did not include a comprehensive assessment of attentional and executive functions, hence limiting our ability to assess their contribution to the Virtual Shop. Second, our goal was to create a scenario involving a task common in daily life and which requires memory processes. However, the task was not designed to measure fine memory processes and in particular, the capacity to bind an item to its spatial and/or temporal context, a condition which might be closer to contemporary definitions of episodic memory (see Pause et al. 2013, for a discussion of the characteristics that would be required for a task to reflect episodic memory). Other types of VR scenarios might be more amenable to measuring binding processes for instance memorizing items and their locations in a town as was done by Plancher et al. (2010) or retrieving details of different scenarios seen in different rooms such as done by Zlomuzica, Preusser, Totzeck, Dere and Margraf (2016) and Zlomuzica et al. (2018). Third, the traditional memory test that we used to assess construct validity differs from the Virtual Shop task on a number of dimensions: it relies on *orally presented* material rather than *image-based verbal* material and it provides semantic orientation at encoding. Finally, there are some methodological aspects that were not addressed here in this study such as the test-retest reliability of the Virtual Shop task, the sense of presence or adverse reactions to VR such as symptoms of cybersickness. While the use of IVR might be advantageous, presence of cybersickness symptoms might be seen as a drawback when using the procedure in clinical populations. Very little is known regarding the presence and severity of cybersickness symptoms in clinical populations and it is critical that future studies provide data regarding the tolerability of VR in patients suffering from various health conditions. Yet, it is important to mention that the procedure was well tolerated in the present group of younger and older adults suggesting that those symptoms might not represent a major obstacle to use the procedure in healthy older adults.

5. Conclusion

In summary, the Virtual Shop task is a feasible and valid tool to assess everyday memory in complex conditions that are close to real-life situations in both younger and older adults. Both age groups were able to complete the task within the virtual environment as well as to navigate and select the virtual objects in a reasonable amount of time. Both construct and ecological validity of the Virtual Shop were supported by our data: the task was sensitive to aging, was correlated with a traditional memory task and was related to an everyday measure of shopping abilities. Importantly, we found that the Virtual Shop was better correlated with participants' assessment of their memory ability in real-life than the traditional episodic memory measure. We also found that it was correlated with measures reflecting processing speed. The Virtual Shop task is therefore an interesting tool to reflect memory in an everyday context but other cognitive functions are solicited as well. The Virtual Shop task has great potential to assess performance in persons suffering from very mild memory impairment or in those with SCD who are concerned about their memory but remain unimpaired on traditional tasks. Because the Virtual Shop task is likely reflecting a number of cognitive process including memory and processing speed, it might be more sensitive to a range of very mild cognitive impairment. It has also great potential to measure whether the positive effects of cognitive interventions transfer to real life. Finally, the Virtual Shop or similar virtual reality scenarios have tremendous potential as ecologically validated tools to train cognition in different populations. They might be particularly useful to promote transfer to everyday life for example by allowing participants to practice newly learned strategies in environments that are close to the ones where they will need to apply them. These are approaches that our research team is currently testing.

Conflict of interest

The authors declare that they have no conflict of interest.

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References

Aguirre, G. K., & D'Esposito, M. (1997). Environmental knowledge is subserved by separable dorsal/ventral neural areas. *The Journal of Neuroscience, 17*(7), 2512–2518.

Allain, P., Foloppe, D. A., Besnard, J., Yamaguchi, T., Etcharry-Bouyx, F., Le Gall, D., . . . Richard, P. (2014). Detecting everyday action deficits in Alzheimer's disease using a nonimmersive virtual reality kitchen. *Journal of the International Neuropsychological Society, 20*(05), 468–477. doi:10.1017/S1355617714000344

Ambrose, A. F., Noone, M. L., Pradeep, V., Johnson, B., Salam, K., & Verghese, J. (2010). Gait and cognition in older adults: Insights from the Bronx and Kerala. *Annals of Indian Academy of Neurology, 13*(6), 99–103. doi:10.4103/0972-2327.74253

Armstrong, C. M., Reger, G. M., Edwards, J., Rizzo, A. A., Courtney, C. G., & Parsons, T. D. (2013). Validity of the Virtual Reality Stroop Task (VRST) in active duty military. *Journal of Clinical and Experimental Neuropsychology, 35*(2), 113–123. doi:10.1080/13803395.2012.740002

Banville, F., Nolin, P., Lalonde, S., Henry, M., Dery, M.-P., & Villemure, R. (2010). Multitasking and prospective memory: Can virtual reality be useful for diagnosis? *Behavioural Neurology, 23*(4), 209–211. doi:10.3233/BEN-2010-0297

Beauchet, O., Dubost, V., Aminian, K., Gonthier, R., & Kressig, R. W. (2005). Dual-task-related gait changes in the elderly: Does the type of cognitive task matter? *Journal of Motor Behavior, 37*(4), 259–264. doi:10.1037/t00930-000

Bennett, D. A., Wilson, R. S., Schneider, J. A., Evans, D. A., Beckett, L. A., Aggarwal, N. T., . . . Bach, J. (2002). Natural history of mild cognitive impairment in older persons. *Neurology*, *59*(2), 198–205. doi:10.1212/WNL.59.2.198

Biocca, F., & Delaney, B. (1995). Immersive virtual reality technology. In F. Biocca and M.

R. Levy (Eds.), *Communication in the age of virtual reality* (pp. 57–124). Hillsdale, NJ: Erlbaum.

Brodeur, M. B., Dionne-Dostie, E., Montreuil, T., & Lepage, M. (2010). The Bank of Standardized Stimuli (BOSS), a new set of 480 normative photos of objects to be used as visual stimuli in cognitive research. *PloS ONE, 5*(5), e10773, 1–13. doi:10.1371/journal.pone.0010773

Bryan, J., & Luszcz, M. A. (1996). Speed of information processing as a mediator between age and free-recall performance. *Psychology and Aging*, *11*(1), 3–9. doi:10.1037/0882-7974.11.1.3

Chaytor, N., & Schmitter-Edgecombe, M. (2003). The Ecological Validity of Neuropsychological Tests: A Review of the Literature on Everyday Cognitive Skills. *Neuropsychology Review, 13*(4), 181–197. doi:10.1023/B:NERV.0000009483.91468.fb

Cipresso, P., Albani, G., Serino, S., Pedroli, E., Pallavicini, F., Mauro, A., & Riva, G. (2014). Virtual multiple errands test (VMET): A virtual reality-based tool to detect early executive functions deficit in Parkinson's disease. *Frontiers in Behavioral Neuroscience, 8*(405), 1–11. doi:10.3389/fnbeh.2014.00405

Corriveau-Lecavalier, N., Ouellet, É., Boller, B., & Belleville, S. (2018). Use of immersive virtual reality to assess episodic memory: A validation study in older adults. Neuropsychological rehabilitation, 1–19. doi:10.1080/09602011.2018.1477684

Cronbach, L. J., & Meehl, P. E. (1955). Construct validity in psychological tests. *Psychological Bulletin*, *52*, 281–302. doi:10.1037/h0040957

Cushman, L. A., Stein, K., & Duffy, C. J. (2008). Detecting navigational deficits in cognitive aging and Alzheimer disease using virtual reality. *Neurology, 71*(12), 888–895. doi:10.1212/01.wnl.0000326262.67613.fe

DeVon, H. A., Block, M. E., Moyle-Wright, P., Ernst, D. M., Hayden, S. J., Lazzara, D. J., . . . Kostas-Polston, E. (2007). A psychometric toolbox for testing validity and reliability.

Journal of Nursing Scholarship, *39*(2), 155–164. doi:10.1111/j.1547-5069.2007.00161.x

Findlater, L., Froehlich, J. E., Fattal, K., Wobbrock, J. O., & Dastyar, T. (2013, April). Age-related differences in performance with touchscreens compared to traditional mouse input. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 343–346). ACM.

Fort, I., Adoul, L., Holl, D., Kaddour, J., & Gana, K. (2004). Psychometric properties of the French version of the Multifactorial Memory Questionnaire for adults and the elderly. *Canadian Journal on Aging, 23*(4), 347–357. doi:10.1353/cja.2005.0020

Franzen, M. D., & Wilhelm, K. L. (1996). Conceptual foundations of ecological validity in neuropsychological assessment. In R. J. Sbordone & C. J. Long (Eds.), *Ecological validity of neuropsychological testing* (pp. 91–112). Boca Raton, FL: St. Lucie Press.

Goldstein, G., McCue, M., Rogers, J., & Nussbaum, P. D. (1992). Diagnostic differences in memory test based predictions of functional capacity in the elderly. *Neuropsychological Rehabilitation*, *2*(4), 307–317. doi:10.1080/09602019208401416

Gould, N. F., Holmes, M. K., Fantie, B. D., Luckenbaugh, D. A., Pine, D. S., Gould, T. D., . . . Zarate, C. A. Jr., (2007). Performance on a virtual reality spatial memory navigation task in depressed patients. *American Journal of Psychiatry, 164*(3), 516–519. doi:10.1176/appi.ajp.164.3.516

Head, D., & Isom, M. (2010). Age effects on wayfinding and route learning skills. *Behavioural Brain Research, 209*(1), 49–58. doi:10.1016/j.bbr.2010.01.012

Henry, M., Joyal, C. C., & Nolin, P. (2012). Development and initial assessment of a new paradigm for assessing cognitive and motor inhibition: The bimodal virtual-reality Stroop. *Journal of Neuroscience Methods, 210*(2), 125–131. doi:10.1016/j.jneumeth.2012.07.025

Hertzog, C., Dixon, R. A., Hultsch, D. F., & MacDonald, S. W. S. (2003). Latent Change Models of Adult Cognition: Are changes in processing speed and working memory associated with changes in episodic memory? *Psychology and Aging, 18*(4), 755–769. doi:10.1037/0882-7974.18.4.755

Higginson, C. I., Arnett, P. A., & Voss, W. D. (2000). The ecological validity of clinical tests of memory and attention in multiple sclerosis. *Archives of Clinical Neuropsychology*, *15*(3), 185–204. doi:10.1016/S0887-6177(99)00004-9

Iglói, K., Zaoui, M., Berthoz, A., & Rondi-Reig, L. (2009). Sequential egocentric strategy is acquired as early as allocentric strategy: Parallel acquisition of these two navigation strategies. *Hippocampus*, *19*(12), 1199–1211. doi:10.1002/hipo.20595

IJmker, T., & Lamoth, C. J. (2012). Gait and cognition: The relationship between gait stability and variability with executive function in persons with and without dementia. *Gait & Posture, 35*(1), 126–130. doi:10.1016/j.gaitpost.2011.08.022

Jaeger, B. K., & Mourant, R. R. (2001, October). Comparison of simulator sickness using static and dynamic walking simulators. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* (Vol. 45, No. 27, pp. 1896–1900). SAGE Publications. doi:10.1177/154193120104502709

Jebara, N., Orriols, E., Zaoui, M., Berthoz, A., & Piolino, P. (2014). Effects of enactment in episodic memory: A pilot virtual reality study with young and elderly adults. *Frontiers in Aging Neuroscience, 6*, 1–16. doi:10.3389/fnagi.2014.00338

Jessen, F., Amariglio, R. E., van Boxtel, M., Breteler, M., Ceccaldi, M., Chételat, G., . . . van der Flier, W. M. (2014). A conceptual framework for research on subjective cognitive decline in preclinical Alzheimer's disease. *Alzheimer's & Dementia*, *10*(6), 844–852. doi:10.1016/j.jalz.2014.01.001

Johnson, J. L. (1994). Episodic memory deficits in Alzheimer's disease: A behaviorally anchored scale. *Archives of Clinical Neuropsychology*, *9*(4), 337–346. doi:10.1016/0887-6177(94)90021-3

Kaitaro, T., Koskinen, S., & Kaipio, M. L. (1995). Neuropsychological problems in everyday life: A 5- follow-up study of young severely closed-head-injured patients. *Brain Injury*, *9*(7), 713–727. doi:10.3109/02699059509008227

Lajoie, Y., Teasdale, N., Bard, C., & Fleury, M. (1996). Upright standing and gait: Are there changes in attentional requirements related to normal aging? *Experimental Aging Research*, *22*(2), 185–198. doi:10.1080/03610739608254006

Lalonde, G., Henry, M., Drouin-Germain, A., Nolin, P., & Beauchamp, M. H. (2013). Assessment of executive function in adolescence: A comparison of traditional and virtual reality tools. *Journal of Neuroscience Methods, 219*(1), 76–82. doi:10.1016/j.jneumeth.2013.07.005

Makatura, T. J., Lam, C. S., Leahy, B. J., Castillo, M. T., & Kalpakjian, C. Z. (1999). Standardized memory tests and the appraisal of everyday memory. *Brain Injury*, *13*(5), 355–367. doi:10.1080/026990599121548

Marchal, A., & Nicolas, S. (2003). Normes de production catégorielle pour 38 catégories sémantiques: étude sur des sujets jeunes et âgés. *L'année psychologique, 103*(2), 313–366. doi:10.3406/psy.2003.29639

Martin, K. L., Blizzard, L., Wood, A. G., Srikanth, V., Thomson, R., Sanders, L. M., & Callisaya, M. L. (2013). Cognitive function, gait, and gait variability in older people: A population-based study. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*. *68*(6), 726–732. doi:10.1093/gerona/gls224

Matheis, R. J., Schultheis, M. T., Tiersky, L. A., DeLuca, J., Millis, S. R., & Rizzo, A. (2007). Is learning and memory different in a virtual environment? *The Clinical Neuropsychologist, 21*(1), 146–161. doi:10.1080/13854040601100668

Moffat, S. D., Zonderman, A. B., & Resnick, S. M. (2001). Age differences in spatial memory in a virtual environment navigation task. *Neurobiology of Aging, 22*(5), 787–796. doi:10.1016/S0197-4580(01)00251-2

Moroni, C. & Bayard, S. (2009). Processus d'inhibition: quelle est leur valeur évolutive après

50 ans? *Psychologie & Neuropsychiatrie du vieillissement, 7*, 121–129. doi:10.1684/pnv.2009.0155

Nasreddine, Z. S., Phillips, N. A., Bédirian, V., Charbonneau, S., Whitehead, V., Collin, I., . . . Chertkow, H. (2005). The Montreal Cognitive Assessment, MoCA: A brief screening tool for mild cognitive impairment. *Journal of the American Geriatrics Society, 53*(4), 695–699. doi:10.1111/j.1532-5415.2005.53221.x

Nolin, P., Stipanicic, A., Henry, M., Lachapelle, Y., Lussier-Desrochers, D., & Allain, P. (2016). ClinicaVR: Classroom-CPT: A virtual reality tool for assessing attention and inhibition in children and adolescents. *Computers in Human Behavior*, *59*, 327–333. doi:10.1016/j.chb.2016.02.023

O'Leary-Kelly, S. W., & Vokurka, R. J. (1998). The empirical assessment of construct validity. *Journal of Operations Management*, *16*(4), 387–405. doi:10.1016/S0272-6963(98)00020-5

Park, D. C., Lautenschlager, G., Hedden, T., Davidson, N. S., Smith, A. D., & Smith, P. K. (2002). Models of visuospatial and verbal memory across the adult life span. *Psychology and Aging, 17*(2), 299–320. doi:10.1037//0882-7974.17.2.299

Park, D. C., Smith, A. D., Lautenschlager, G., Earles, J. L., Frieske, D., Zwahr, M., & Gaines, C. L. (1996). Mediators of long-term memory performance across the life span. *Psychology and Aging*, *11*(4), 621–637. doi:10.1037/0882-7974.11.4.621

Parsons, T. D., Carlew, A. R., Magtoto, J., & Stonecipher, K. (2015). The potential of function-led virtual environments for ecologically valid measures of executive function in experimental and clinical neuropsychology. *Neuropsychological Rehabilitation*, 1–31. doi:10.1080/09602011.2015.1109524

Parsons, T. D., & Courtney, C. G. (2014). An initial validation of the virtual reality paced auditory serial addition test in a college sample. *Journal of Neuroscience Methods, 222*, 15–23. doi:10.1016/j.jneumeth.2013.10.006

Pause, B. M., Zlomuzica, A., Kinugawa, K., Mariani, J., Pietrowsky, R., & Dere, E. (2013). Perspectives on episodic-like and episodic memory. *Frontiers in Behavioral Neuroscience, 7, article 33*, 1–12. doi:10.3389/fnbeh.2013.00033

Petersen, R. C., Aisen, P. S., Beckett, L. A., Donohue, M. C., Gamst, A. C., Harvey, D. J., . . . Weiner, M. W. (2010). Alzheimer's disease Neuroimaging Initiative (ADNI) clinical characterization. *Neurology*, *74*(3), 201–209. doi:10.1212/WNL.0b013e3181cb3e25

Plancher, G., Gyselinck, V., Nicolas, S., & Piolino, P. (2010). Age effect on components of episodic memory and feature binding: A virtual reality study. *Neuropsychology, 24*(3), 379–390. doi:10.1037/a0018680

Plancher, G., Nicolas, S., & Piolino, P. (2008). *Réalité virtuelle et mémoire épisodique: étude dans la maladie d'Alzheimer.* Paper presented at the 3èmes journées de l'Association Française de Réalité Virtuelle (AFRV), Bordeaux, France.

Plancher, G., Tirard, A., Gyselinck, V., Nicolas, S., & Piolino, P. (2012). Using virtual reality to characterize episodic memory profiles in amnestic mild cognitive impairment and Alzheimer's disease: Influence of active and passive encoding. *Neuropsychologia, 50*(5), 592–602. doi:10.1016/j.neuropsychologia.2011.12.013

Potvin, M.-J., Rouleau, I., Audy, J., Charbonneau, S., & Giguère, J.-F. (2011). Ecological prospective memory assessment in patients with traumatic brain injury. *Brain Injury, 25*(2), 192–205. doi:10.3109/02699052.2010.541896

Poupyrev, I., Ichikawa, T., Weghorst, S., & Billinghurst, M. (1998, August). Egocentric object manipulation in virtual environments: Empirical evaluation of interaction techniques. In *Computer graphics forum* (Vol. 17, No. 3, pp. 41–52). Blackwell Publishers Ltd.

Rand, D., Katz, N., & Weiss, P. L. (2007). Evaluation of virtual shopping in the VMall: Comparison of post-stroke participants to healthy control groups. *Disability and Rehabilitation*, *29*(22), 1710–1719. doi:10.1080/09638280601107450

Raspelli, S., Pallavicini, F., Carelli, L., Morganti, F., Pedroli, E., Cipresso, P., . . . Riva, G. (2012). Validating the Neuro VR-based virtual version of the Multiple Errands Test:

preliminary results. *Presence: Teleoperators and Virtual Environments, 21*(1), 31–42. doi:10.1162/PRES_a_00077

Renison, B., Ponsford, J., Testa, R., Richardson, B., & Brownfield, K. (2012). The ecological and construct validity of a newly developed measure of executive function: The Virtual Library Task. *Journal of the International Neuropsychological Society, 18*(03), 440–450. doi:10.1017/S1355617711001883

Rizzo, A. A., Schultheis, M., Kerns, K. A., & Mateer, C. (2004). Analysis of assets for virtual reality applications in neuropsychology. *Neuropsychological Rehabilitation, 14*(1-2), 207–239. doi:10.1080/09602010343000183

Rizzo, M., McGehee, D. V., Dawson, J. D., & Anderson, S. N. (2001). Simulated car crashes at intersections in drivers with Alzheimer disease. *Alzheimer Disease & Associated Disorders, 15*(1), 10–20. doi:10.1097/00002093-200101000-00002

Rizzo, M., Reinach, S., McGehee, D., & Dawson, J. (1997). Simulated car crashes and crash predictors in drivers with Alzheimer disease. *Archives of Neurology, 54*(5), 545–551. doi:10.1001/archneur.1997.00550170027011

Rogers, W. A., Fisk, A. D., McLaughlin, A. C., & Pak, R. (2005). Touch a screen or turn a knob: Choosing the best device for the job. *Human Factors*, *47*(2), 271–288. doi:10.1518/0018720054679452

Saposnik, G., & Levin, M. (2011). Virtual reality in stroke rehabilitation a meta-analysis and implications for clinicians. *Stroke, 42*(5), 1380–1386. doi:10.1161/STROKEAHA.110.605451

Sauzéon, H., N'Kaoua, B., Arvind Pala, P., Taillade, M., & Guitton, P. (2016a). Age and active navigation effects on episodic memory: A virtual reality study. *British Journal of Psychology*, *107*(1), 72–94. doi:10.1111/bjop.12123

Sauzéon, H., N'Kaoua, B., Pala, P. A., Taillade, M., Auriacombe, S., & Guitton, P. (2016b). Everyday-like memory for objects in ageing and Alzheimer's disease assessed in a visually complex environment: The role of executive functioning and episodic memory. *Journal of Neuropsychology*, *10*, 33–58. doi:10.1111/jnp.12055

Sauzéon, H., Pala, P. A., Larrue, F., Wallet, G., Déjos, M., Zheng, X., . . . N'Kaoua, B. (2012). The use of virtual reality for episodic memory assessment. *Experimental Psychology*, *59*, 99–108. doi:10.1027/1618-3169/a000131

Siemerkus, J., Irle, E., Schmidt-Samoa, C., Dechent, P., & Weniger, G. (2012). Egocentric spatial learning in schizophrenia investigated with functional magnetic resonance imaging. *NeuroImage: Clinical, 1*(1), 153–163. doi:10.1016/j.nicl.2012.10.004

Sirois, M., Kremin, H., & Cohen, H. (2006). Picture-naming norms for Canadian French: Name agreement, familiarity, visual complexity, and age of acquisition. *Behavior Research Methods, 38*(2), 300–306. doi:10.3758/BF03192781

Smith, M. W., Sharit, J., & Czaja, S. J. (1999). Aging, motor control, and the performance of computer mouse tasks. *Human factors*, *41*(3), 389–396. doi:10.1518/001872099779611102

Snodgrass, J. G., & Vanderwart, M. (1980). A standardized set of 260 pictures: Norms for name agreement, image agreement, familiarity, and visual complexity. *Journal of Experimental Psychology: Human learning and memory*, *6*(2), 174–215. doi:10.1037/0278-7393.6.2.174

Strauss, E., Sherman, E. M., & Spreen, O. (2006). *A compendium of neuropsychological tests: Administration, norms, and commentary*, third edition, New York, NY: Oxford University Press.

Sunderland, A., Harris, J. E., & Baddeley, A. D. (1983). Do laboratory tests predict everyday memory? A neuropsychological study. *Journal of Verbal Learning and Verbal Behavior*, *22*(3), 341–357. doi:10.1016/S0022-5371(83)90229-3

Tarnanas, I., Laskaris, N., Tsolaki, M., Muri, R., Nef, T., & Mosimann, U. P. (2015). On the comparison of a novel serious game and electroencephalography biomarkers for early dementia screening. In P. Vlamos and A. Alexiou (Eds.), *GeNeDis 2014. Advances in Experimental Medicine and Biology* (Vol. 821, pp. 63–77). Springer, Cham.

doi:10.1007/978-3-319-08939-3_11

Tarnanas, I., Schlee, W., Tsolaki, M., Müri, R., Mosimann, U., & Nef, T. (2013). Ecological validity of virtual reality daily living activities screening for early dementia: Longitudinal study. *JMIR Serious Games, 1*(1), e1. doi:10.2196/games.2778

Tremblay, M. P., Potvin, O., Belleville, S., Bier, N., Gagnon, L., Blanchet, S., . . . Hudon, C. (2016). The Victoria Stroop test: Normative data in Quebec-French adults and elderly. *Archives of Clinical Neuropsychology, 31*(8), 926–933. doi:10.1093/arclin/acw029

Troyer, A. K., Leach, L., & Strauss, E. (2006). Aging and response inhibition: Normative data for the Victoria Stroop Test. *Aging, Neuropsychology, and Cognition*, *13*(1), 20–35. doi:10.1080/138255890968187

Troyer, A. K., & Rich, J. B. (2002). Psychometric properties of a new metamemory questionnaire for older adults. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences, 57*(1), 19–27. doi:10.1093/geronb/57.1.P19

Usoh, M., Arthur, K., Whitton, M. C., Bastos, R., Steed, A., Slater, M., & Brooks, F. P. Jr., (1999, July). Walking> walking-in-place> flying, in virtual environments. In *Proceedings of the 26th annual conference on Computer graphics and interactive techniques* (pp. 359-364). ACM Press/Addison-Wesley Publishing Co.

Vallejo, V., Wyss, P., Chesham, A., Mitache, A. V., Müri, R. M., Mosimann, U. P., & Nef, T. (2017). Evaluation of a new serious game based multitasking assessment tool for cognition and activities of daily living: Comparison with a real cooking task. *Computers in Human Behavior*, *70*, 500–506. doi:10.1016/j.chb.2017.01.021

Van der Linden, M., Coyette, F., Poitrenaud, J., Kalafat, M., Calacis, F., Wyns, C., . . . et les membres du GREMEM (2004). L’épreuve de rappel libre/rappel indicé à 16 items (RL/RI-16). In M. Van der Liden, S. Adam, A. Agniel, C. Baisset Mouly, et al. (Eds.), *L’évaluation des troubles de la mémoire : Présentation de quatre tests de mémoire épisodique (avec leur étalonnage).* Marseille, France : Solal.

Waller, D., Knapp, D., & Hunt, E. (2001). Spatial representations of virtual mazes: The role of visual fidelity and individual differences. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 43*(1), 147–158. doi:10.1518/001872001775992561

Wechsler, D. (1997). *Wechsler Memory Scale–Third Edition*. San Antonio, TX: The Psychological Corporation. Traduction – adaptation québécoise par Claude Paquette (2000).

Weniger, G., & Irle, E. (2008). Allocentric memory impaired and egocentric memory intact as assessed by virtual reality in recent-onset schizophrenia. *Schizophrenia Research, 101*(1), 201–209. doi:10.1016/j.schres.2008.01.011

Weniger, G., Ruhleder, M., Lange, C., Wolf, S., & Irle, E. (2011). Egocentric and allocentric memory as assessed by virtual reality in individuals with amnestic mild cognitive impairment. *Neuropsychologia*, *49*(3), 518–527. doi:10.1016/j.neuropsychologia.2010.12.031

Weniger, G., Ruhleder, M., Wolf, S., Lange, C., & Irle, E. (2009). Egocentric memory impaired and allocentric memory intact as assessed by virtual reality in subjects with unilateral parietal cortex lesions. *Neuropsychologia*, *47*(1), 59–69. doi:10.1016/j.neuropsychologia.2008.08.018

Weniger, G., Siemerkus, J., Schmidt-Samoa, C., Mehlitz, M., Baudewig, J., Dechent, P., & Irle, E. (2010). The human parahippocampal cortex subserves egocentric spatial learning during navigation in a virtual maze. *Neurobiology of Learning and Memory, 93*(1), 46–55. doi:10.1016/j.nlm.2009.08.003

Werner, P., Rabinowitz, S., Klinger, E., Korczyn, A. D., & Josman, N. (2009). Use of the Virtual Action Planning Supermarket for the Diagnosis of Mild Cognitive Impairment. *Dementia and Geriatric Cognitive Disorders, 27*(4), 301–309. doi:10.1159/000204915

Witmer, B. G., & Singer, M. J. (1998). Measuring presence in virtual environments: A presence questionnaire. *Presence: Teleoperators and virtual environments, 7*(3), 225–240. doi:10.1162/105474698565686

Woollacott, M., & Shumway-Cook, A. (2002). Attention and the control of posture and gait: A review of an emerging area of research. *Gait & Posture, 16*(1), 1–14. doi:10.1016/S0966-6362(01)00156-4

Zlomuzica, A., Preusser, F., Totzeck, C., Dere, E., & Margraf, J. (2016). The impact of different emotional states on the memory for what, where and when features of specific events. *Behavioural Brain Research*, *298*, 181–187. doi:10.1016/j.bbr.2015.09.037

Zlomuzica, A., Woud, M. L., Machulska, A., Kleimt, K., Dietrich, L., Wolf, O. T., . . . Margraf, J. (2018). Deficits in episodic memory and mental time travel in patients with post-traumatic stress disorder. *Progress in Neuro-Psychopharmacology and Biological Psychiatry, 83*, 42–54. doi:10.1016/j.pnpbp.2017.12.014

Zygouris, S., Giakoumis, D., Votis, K., Doumpoulakis, S., Ntovas, K., Sofia, S., . . . Tsolaki, M. (2014). Can a Virtual Reality Cognitive Training Application Fulfill a Dual Role? Using the Virtual Supermarket Cognitive Training Application as a Screening Tool for Mild Cognitive Impairment. *Journal of Alzheimer's Disease, 40*, 1–10. doi:10.3233/JAD-141260

Chapitre III

Article 2

Article 2

Memory training in older adults with a memory complaint: the use of virtual reality to assess and promote transfer

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ABSTRACT

In this study we use immersive virtual reality (VR) to measure transfer following strategic memory training in older adults and to assess whether efficacy and transfer are increased when training is complemented by practice in an immersive virtual environment. This was a double-blind randomized controlled design. Forty-seven older adults with a subjective memory complaint were trained with the method of loci but they either practiced the strategy in VR (VR+) or were familiarized with VR using a non-memory task (VR-). Training efficacy was measured with word recall; transfer of the training benefit was measured with a recall task completed in two VR scenarios as well as a self-reported memory questionnaire. Testing was administered before training (PRE), midway through (POST 3) and after (POST 6). Participants improve their performance on word recall. Transfer is observed on the two virtual scenarios but not on the memory questionnaire. Improvement is found when comparing PRE to POST 3 with no further improvement at POST 6. Thus, strategic memory training improves the memory of seniors with a memory complaint and this benefit is transferred to VR tasks that are close to real life. However, providing exercises in VR does not increase efficacy and transfer.

Keywords: cognitive training, memory training, virtual reality, virtual environment, episodic memory, aging, memory complaint.

INTRODUCTION

Memory failure is a primary source of concern in older adults hence it has been a target for cognitive intervention programs. Memory training generally involves the teaching of mnemotechnics that are known to improve the quality of encoding and that facilitate retrieval later on (Willis & Belleville, 2016). Strategic memory training is found to increase memory performance in healthy seniors (e.g., Ball et al., 2002; Engvig et al., 2010) as well as persons with mild cognitive impairment (MCI) (Belleville et al., 2006; Akhtar, Moulin, & Bowie, 2007; Hampstead et al., 2008; Kinsella et al., 2009; Lim et al., 2012; Olchik et al., 2013). The discovery that older adults remain capable of learning new memory strategies has advanced the field, as since it demonstrates that cognition and the brain remain plastic even in old age. Yet, the ultimate goal of cognitive training is not to improve memory for words learned in experimental contexts, but to transfer and improve memory in everyday life. Transfer refers to the idea that training one cognitive function, or one set of material, will improve performance on untrained functions or materials (Perkins & Salomon, 1992; Noack et al., 2009; Austin, 2009; Butterfield & Nelson, 1991; Mayer & Wittrock, 1996). Content *transfer* refers to improvement on cognitive abilities or tasks that use cognitive processes similar to those that were trained. For instance, content transfer may be measured by examining whether learning to memorize visual material results in improved learning of auditory material. In turn, *context transfer* occurs when a behavior or a strategy learned in one context is successfully applied or leads to improvement in a different context (Bransford et al., 2000; Perkins & Salomon, 1992; Perkins & Salomon, 1988; Lobato, 2006). Transferring training effects from the clinic or laboratory to activities in real life is one of the most sought-after *context transfers*.

Generating *context transfer* following cognitive training in elderly people is challenging and evidence is scarce in literature (for reviews, see; Zelinsly, 2009; Rebok et al., 2007; Simons et al., 2016). The lack of clear evidence for transfer in real life has been raised as one of the major limitations for recommending cognitive training as a tool to reduce or reverse cognitive decline in older adults (Statement from Max Planck Institute for Human Development and Stanford Center on Longevity, accessed 2016).

One major challenge relates to the difficulty in measuring it accurately. Indeed, most studies measured *context transfer* with self-reported questionnaires where participants are asked to judge their memory capacities in different everyday life situations. Measuring transfer with self-reported questionnaire leads to inconsistent findings. For instance, a recent randomized controlled study which compared a strategy-based memory training condition to psychosocial intervention and a no-contact control conditions in older adults with MCI, was unable to observe transfer on self-reported measures of complex activities of daily living, however participants reported an increased use of memory strategies in everyday life (Belleville et al., 2018). In the ACTIVE randomized controlled trial, memory-trained participants reported less difficulty performing daily activities compared to controls, but only at the 10-year follow-up (Ball et al., 2002; Willis et al., 2006; Rebok et al., 2014). Finally, a recent meta-analysis reported positive, but small, effects of cognitive training on activities of daily life activity questionnaires, as well as on metacognitive measures in older adults with

MCI (Chandler, Parks, Marsiske, Rotblatt, & Smith, 2016). Relying on self-reported measures has its limitations because they require good metacognitive abilities and are easily influenced by variables such as mood or personality. Thus, the validity and sensitivity of self-report questionnaires to measure *context transfer* might account in part for small and inconsistent effects that are reported in the literature. Therefore, more appropriate measures of *context transfer* are necessary.

Another reason that may explain the limited evidence for *context transfer* training relates is how training programs are delivered. Transfer is facilitated when there are similarities between the learning experience and the context where the training will be applied. Yet training is generally provided through classroom-based and instructor focused-exercises, performed in laboratory settings or with computer exercises, both differ largely from conditions in everyday life. This can increase the challenge for seniors when it comes attempting to apply the strategies. When placed in an environment which is different from the one where they were trained, trainees might fail to recognize situations that are appropriate to apply the learned strategies or might perceive them as inapplicable or inappropriate (Elangovan & Karakowsky, 1999). Thus, training programs should be designed in a way that promotes transfer. This can be done by providing exercises in a context which is close to the environment or by reproducing the conditions where trainees will apply strategies (Elangovan & Karakowsky, 1999; Yorks, 2003). Some studies have been attempting to encourage transfer by using verbal exercises that contain scripts of practical situations (Jobe et al., 2001; Ball et al., 2002; Willis et al., 2006; Brum et al., 2009; Belleville et al., 2006; Rapp, Brenes, & Marsh, 2002; Troyer et al., 2008), but several failed to find evidence for *context transfer* (Ball et al., 2002; Willis et al., 2006; Rapp et al., 2002; Troyer et al., 2008). This could be because those scripts were still provided in classroom environments, thus remaining artificial and relatively distant from complex real-life memory tasks. Lastly, they provided homework where the quality of the training could not be easily controlled.

Virtual reality (VR) has the potential to be able to measure and promote *context transfer*. VR is a computer-based technology that allows users to interact with a multisensory simulated environment in real time (Saposnik & Levin, 2011). It allows the creation of environments and tasks that mimic real life situations (Rizzo et al., 2004), and several studies have demonstrated its feasibility (Corriveau-Lecavalier, Ouellet, Boller, & Belleville, 2018; see Rose, Brooks, & Rizzo, 2005; Shuchat, Ouellet, Moffat, & Belleville, 2012, for reviews), its validity to measure cognition (Jian & Li, 2007, Gould et al., 2012; Gonneaud et al., 2012; Plancher et al., 2010; Jebara et al., 2014; Corriveau-Lecavalier et al., 2018; Ouellet, Boller, Corriveau-Lecavalier, Cloutier, & Belleville, 2018) as well as its ecological validity to reflect real life cognition (Waller, Knapp & Hunt, 2001; Zhang et al., 2003; Cushman, Stein, & Duffy, 2008; Widmann, Beinhoffa, & Riepea, 2012; Sorita et al., 2013; Allain et al., 2014; Parson et al., 2015, Ouellet et al. 2018). VR can be used to develop complex training environments close to the real-world while allowing precise control of stimulus presentations and response collection (Rizzo et al., 1997).

A few cognitive training studies have relied on VR and reported beneficial impact on real-life measures. For example, training to do shopping in a virtual supermarket was found to improve shopping skills in real-life situation (Cromby et al., 1996; Yip & Man, 2013). Training in a virtual replica of a hospital (Brooks, 1999) or a city district (Wallet et al., 2009; Wallet et al., 2013) improved route navigation abilities in the corresponding real environments. Thus, a few studies suggest that providing training in a virtual environment can transfer to similar real-life situations. However, none of these studies have explored whether adding VR exercises to a cognitive intervention previously known to improve cognitive performance can increase its transfers effects. Randomized studies measuring the added-value of immersive VR training in older adults are little to none.

This study had three principal goals: 1) assess *context transfer* with VR and compare it to self-reported questionnaires 2) test whether including VR in training can increase *context transfer* effects by providing training conditions that are close to real life situations; 3) assess if efficacy and *context transfer* vary with the number of training sessions (Lampit et al 2014; Schwaighofer, Fisher, & Bühner, 2015), as it is possible that transfer requires a larger dose than efficacy measures in order to observe an effect.

Participants received a classroom-based memory strategy training with the method of loci and those in the experimental condition group practiced what was taught in a fully immersive 3D virtual reality convenience store, the *Virtual Shop*. Participants randomized in the active control group received memory training but did not practice the strategy in the virtual environment (VR). Performance on a classical word-memory task provided information on training efficacy and near *content transfer*. Context transfer was measured with a VR task where participants memorized and retrieved an errand list in a Virtual Shop similar to the one where they received training, with another VR task where they learned words while finding directions in a Virtual Car Ride, and a self-report questionnaire where participants rated their everyday memory ability. The self-report questionaire was used to compare VR-based transfer to transfer assessed with more traditional self-reported measures of *context transfer*. We assessed efficacy and transfer halfway through and at the end of training to examine how efficacy and transfer build-up with more training dose sessions (Lampit et al 2014; Schwaighofer, Fisher, & Bühner, 2015). This will allow us to assess whether insufficient dosage might account for the lack of solid transfer effects in previous studies.

METHOD

Participants

Fifty-four older participants with a subjective cognitive decline (SCD) were recruited from the community through advertisements in community centers, public conferences and magazines for seniors. The sample size was based on a power analysis that expects a large effect size for memory strategy training (e.g., Belleville et al., 2006) and considers a drop-out rate of about 10 %. Participants met the SCD criteria proposed by Jessen et al. (2014), where they complained about their memory but are cognitively intact. Complaints were confirmed by asking participants if they believed their memory was getting worse. To ensure that participants were cognitively intact, we had them complete extensive neuropsychological tests (see below). Other inclusion criteria were being older than 50 years of age, fluent in French, and having normal or corrected vision and hearing.

Participants were dismissed if they self-reported balance problems, substance abuse, presence or history of a neurological disorder, stroke or severe traumatic brain injury, presence or history of a severe psychiatric disorder (e.g., schizophrenia, post-traumatic stress disorder, recurrent episodes of major depression), fibromyalgia, uncontrolled sleep apnea, fatal disease (e.g., cancer), general anaesthesia in the past 6 months, a diagnosis of MCI or dementia.

An initial phone interview was used to assess if participants had a memory complaint and to screen for exclusion criteria. Those who were deemed eligible based on the phone interview were invited to complete a more thorough clinical and neuropsychological assessment to confirm that they met inclusion criteria and to observe their characteristics. Clinical tests included the Geriatric Depression Scale (GDS; Yesavage et al., 1983), the Hachinski Scale (Hachinski et al., 1975), the Charlson Comorbidity Index (Charlson et al., 1987), and the Activities of Daily Living-Prevention Instrument (ADL-PI, from ADCS; Galasko et al., 2006). These measures aimed to well-characterized the studied sample in order to compare it with those recruited in other intervention studies. Cognitive tests used to determine normal cognition included the Montreal Cognitive Assessment (MoCA; Nasreddine et al., 2005), two tests of episodic memory (RL/RI-16; Van der Linden & Adam, 2004; Logical Memory I subtest, LM I [French version]; from Wechsler Memory Scale III, 1997), a test of language (Boston Naming Test, BNT; Kaplan, Goodglass, & Weintraub, 1978), one test of executive functions (Stroop-Victoria; Troyer, Leach, & Strauss, 2006; French adaptation from Moroni & Bayard, 2009; Norms from Tremblay et al., 2016), and one test of crystallised intelligence (Vocabulary subtest; Wechsler Adult Intelligence Scale IV, 2008). The cut-off for a normal score on the MoCA was ≥ 26 (Nasreddine et al., 2005). Performance on RL/RI, BNT, Stroop-Victoria and Vocabulary was deemed normal when scores were no more than 1.5 standard deviations below the mean of age- and education- matched normative samples. The score on LM1 was considered normal based on education-adjusted cut-off scores used in the Alzheimer's Disease Neuroimaging Initiative study (ADNI, Bennett et al., 2002).

Design

This was a two-arm randomized active-controlled design (parallel-group, block randomization, $N = 8$. Group allocation was made by the ALEA function of Excel blind to pre-post testing) with three time-point measurements (see Figure 1). All participants received memory training with the method of loci but the VR experience differed depending on what group participants were a part of. Half of the participants were randomly put in the VR training group where they received memory exercises with method of loci in a virtual shop (VR+), and half were put in to an active control condition group where they were placed in the same virtual environment but only performed visuo-motor tasks (VR-). This condition was used as an active control to ensure that the improvement in transfer task was not because the VR+ participants were more familiar with VR or with the response procedure. The training was given over six 1-hour sessions provided every other day, during weekdays over 2 weeks (1 session per day, 3 sessions per week). Outcome measures were taken no more than one week prior to training (PRE), 1 week after the third training session (POST 3) and no more than one week following the end of the training (POST 6)[2]. Efficacy was measured with immediate recall of words auditorily presented, using a task that was different from trained task in the stimuli's modality, thus considered as a near content transfer. *Context transfer* was measured with two immersive VR memory tasks (the Virtual Shop and the Virtual Car Ride) and a self-reported questionnaire measuring memory ability. Parallel versions of memory measure were used for each of the testing phases. The study was double-blind: the examiner was blind to the participant's training allocation and participants were unaware of the two different VR training conditions. To reduce expectancy, and enforce double-blinding, the consent form mentioned only that the participant would have to *complete exercises in virtual reality that consist in searching and buying products in a shop* and hence no mention was made of randomization. To minimise performance variability due to circadian effects, individual participants were evaluated at the same time of day (morning or afternoon) for the three outcomes sessions. The study was conducted at Research Center of the Institut universitaire de gériatrie de Montréal (CRIUGM). The protocol was approved by the Comité mixte d'éthique de la recherche du Regroupement Neuroimagerie / Québec (CMER-RNQ) and all participants completed a written informed consent form prior to study participation.

[2] The self-reported questionnaire was completed only at PRE and POST 6. The questionnaire refers to the past two weeks and hence, the time that would have been covered by a POST 3 would have overlap with that of PRE.

Figure 1. Study design

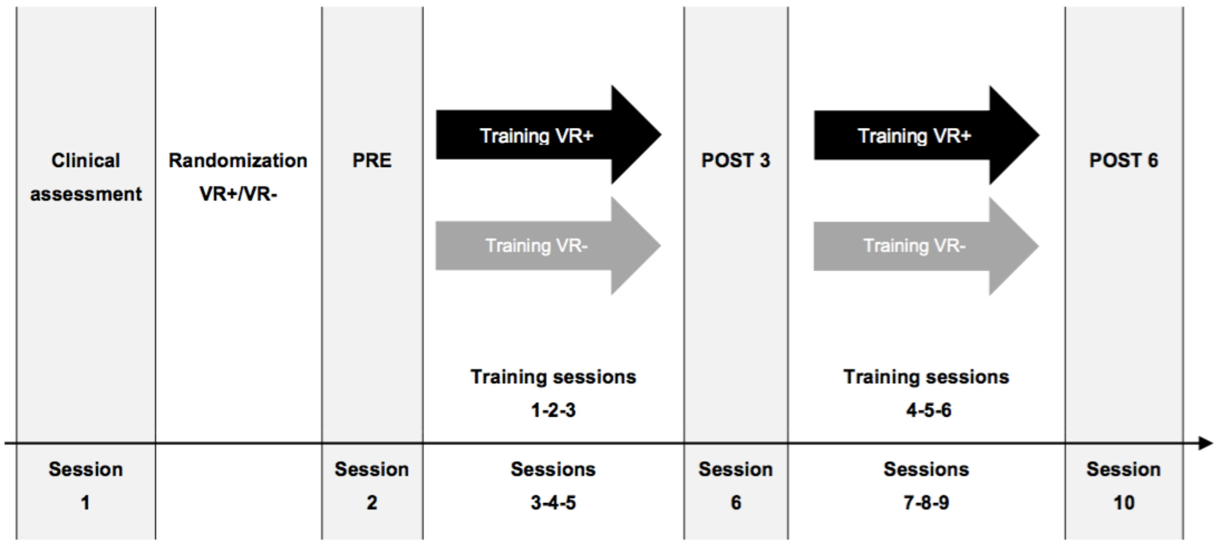

Figure 1. The figure shows the design from session 1 to 10 in the study. Black (VR+) and grey (VR-) arrows represent the differences between the two randomized conditions.

Intervention

The method of loci is a well-known mnemonic strategy that relies on mental imagery and associative memory, where participants mentally associate items with a familiar sequence of loci situated in their own environment (Lea, 1975). First, participants identify and learn a set of loci in a familiar route, most often their house or apartment. They then learn to associate each loci with words or events. At encoding, interactive visual imagery is used to associate the item and its locus in serial order (i.e. the n^{th} word is associated to the n^{th} locus). When the list has to be recalled, the participant mentally goes through its mental route, retrieving the associated image at each locus (Verhaeghen & Marcoen, 1996).

The method of loci was used here by adapting the content from the MEMO program (Belleville et al., 2006; Gilbert et al., 2008; Belleville et al., 2018). The number of sessions and trials was increased relative to the original MEMO program. Each session included a face-to-face teaching of the method of loci in small groups (2-4 participants) which lasted about 50 minutes. This was followed by individual exercises in the Virtual Shop (VR+ or VR-) which took about around 10 minutes to complete. Session 1 comprised exercises to improve mental imagery and teach participants to create interactive mental images. Participants were encouraged to create bizarre, distinctive and/or funny interactive images as these are known to enrich the memory trace and facilitate retrieval. The method of loci was then presented and participants were asked memorised a mental route with 12 familiar loci from their home. Session 2 started with a review of the steps involved in the method of loci and of participant's individual route. The method was then practiced using lists of concrete and imaginable words visually presented from an individual PC computer run by E-prime 2 (Psychology Software Tools, Sharpsburg, PA). The instructor asked the participant to describe their interactive mental images for the first exercises so that guidance and feedback on the quality of the interactive images could be provided. Sessions 3 to 6 included additional exercises with varying lists of 12 concrete words that participants were instructed to encode and retrieve with the method of loci. Feedback on performance and interactive images continued to be provided. The difficulty level was increased gradually over these sessions by shortening the time allowed to create the interactive images and by reducing feedback and guidance[3].

The Virtual Shop

The Virtual Shop (see figure 2) environment is a three-dimensional and fully immersive virtual convenience store in which the participant can move freely to search for common shopping objects (Ouellet et al., 2018, Corriveau-Lecavalier et al., 2018). The VR system is installed in an empty room which size is equivalent to that of the Virtual Shop so that participants can actually move in the environment that they see through an audio-visual Head Mounted Display (HMD). They navigate in the VR environment by physically walking in the room. A handheld device is used to point and select virtual objects.

[3] The training protocol also included an attentional training received by half of the participants in each VR groups. The attentional training did not have any effect on either efficacy or transfer measures and hence will not be further discussed here for sake of simplicity.

Figure 2. The Virtual Shop

a. b.

Figure 2. a. A participant immersed in the Virtual Shop. b. Screen shot captured from the Virtual Shop.

When immersed in the environment, participants allocated to the VR+ condition practiced the method of loci. They first encoded a list of six common shopping objects (e.g., milk, candles, etc.) which were visually presented one-by-one on a virtual notepad. A virtual cashier then engaged in a conversation to create interference. After 20 seconds, the cashier instructed the participant to walk in the store to get the objects from the list. The six objects were randomly placed in different locations within the store. The store also contained six distractor objects which belonged to the same semantic category as the learned objects. The participant was free to explore the store as they wished and there was no time limit to retrieve the objects.

Participants allocated to the VR- condition were presented the same objects as for the VR+ condition and they were asked to find the objects in the store. The main difference was that only one object was presented at a time and it remained in view until it was found and selected. As the object remained visible, the procedure did not involve memory, nor did it require to use the method of loci as only one object was processes at a given time. The procedure was repeated for the six objects from the list. Thus, this active control condition controlled for exposure to the Virtual Shop environment, objects and characters, and to the manipulation of the device used to select objects. This was critical to ensure that improvement on the transfer task was not due to increased practice with the VR environment by the experimental group.

Outcomes measures

Measure of efficacy (near content transfer)

A word recall task was used to measure training efficacy. Participants were asked to memorise two lists of 12 words. Items were presented auditorily at a rate of one item every 5 seconds and recall was done by writing. Because testing efficacy was done using a different modality than the one used during training, this can be interpreted as reflecting near content transfer. Words were presented using the E-prime 2 software with Plantronix Audio 550 headphones. The mean number of words correctly recalled (in any order) was used as the dependent variable.

Measures of context transfer

The Virtual Shop (near context transfer). The participant was immersed in a Virtual Shop environment using a physical layout of a shop different from the one used during training. The physical appearance of the shops used in the training and testing phases differed in terms of the placement and orientation of the shelves as well as the colors and material of the shelves, floor and walls. While in the shop, the participant was asked to memorise, find and select 12 objects. Objects were first presented on a notepad like the one used in the training environment at a rate of one object every 5 seconds. This was followed by a 20-second conversation with the cashier where he asked questions regarding the soccer game seen on television and the time indicated on the clock. Following the interference period participants were asked to find the learned objects in the shop and select each of them by pointing them with a remote control. The learned objects were placed randomly in the store among 12 distractor objects which belonged to the same semantic categories as the target items. The number of learned objects correctly recalled (i.e. selected and validated) was used as the dependant variable. Encoding and retrieval were done in a noisy environment: participants heard conversations which consisted of two short texts read respectively by male and a female and presented dichotically through the HDM headphones. This task was found to be feasible and valid in a prior study (Ouellet et al., 2018, Corriveau-Lecavalier et al., 2018).

The Virtual Car Ride (far context transfer). The participant was immersed in a 3D virtual car in where he/she was a passenger giving the driver directions to Chauminont, a fictitious city. The virtual car was moving on a highway and road signs indicating directions to Chauminont, and along with other city names, were shown along the way. The participant was instructed to detect the road signs indicating directions for Chauminont by pressing a button. Using their left index finger, participants pressed the left mouse button each time they saw Chauminont's name on a road sign. A recording of a radio station broadcast about traffic reports was used as verbal noise during the task. Concurrently, a list of 12 concrete words was read by a male voice at a rate of one word every 5 seconds. The participant was asked to encode and verbally recall the words immediately after presentation of the list, while identifying the Chauminont road boards. The Virtual car ride ended when the participant finished reporting the words. Thus, it lasted about 4 minutes and included a maximum of 40 road signs, half of them targets, and half distractors. Memory performance, i.e. the number of words correctly recalled, and accuracy in detecting road boards signs, i.e. [(hits minus false alarms)/number of targets presented], served as dependant variables.

The *Multifactorial Memory Questionnaire* (MMQ). The MMQ is a well validated self-report questionnaire measuring memory in everyday life (Troyer & Rich, 2002; French version: Fort, Adoul, Holl, Kaddour, & Gana, 2004). Here we focused on the Ability subscale of the MMQ which comprises 20 items where participants rate how often they encountered memory difficulties in their daily life (e.g., How often do you forget to pay a bill on time; How often do you misplace something you use daily like your keys or glasses, etc.) over the last two weeks, on a scale from *all the time* (1) to *never* (5). The internal consistency of the French version of this scale, measured by Cronbach's alpha, was highly reliable, $\alpha = 0.88$. (Fort et al., 2004). Only the Ability subscale of the MMQ was used from the three subscales available. The contentment scale is a measure of effect regarding memory and hence was not used as it does not reflect transfer as such. The Strategy subscale measures the number of strategies that people use in their daily life, therefore it was not judged as appropriate as since only one strategy was learned here.

Statistical analyses

All data were analyzed using *Statistical Package for Social Sciences* (SPSS) version 21.0. Independent *t*-tests (two-tailed) and chi-square tests were used to evaluate between-group differences at baseline. To assess efficacy on the word recall task and transfer on the Virtual Shop and the Virtual Car Ride, separate mixed analysis of variance (ANOVA) were conducted with Condition (VR+; VR-) as a between-subject factor and Phase (PRE; POST 3; POST 6) as a within-subject factor. Word recall was used as a dependent variable for the measure of training efficacy and the Virtual Shop. For the Virtual Car Ride, word recall and accuracy level on the detection task were analyzed as separate dependant variables. Transfer measured with the Ability score from the MMQ was analyzed with Condition (VR+; VR-) as a between-subject factor and Phase (PRE; POST 6) as a within-subject factor. Paired comparisons were then conducted for post hoc analyses. A main Phase effect is expected for efficacy on near content transfer measures and a Phase x Condition is expected on context transfer measures reflecting greater transfer in the VR+ than VR- condition. *Pearson* bivariate correlations (one-tailed) were computed to assess the relationship between change scores on measures of efficacy and change scores on measures of transfer at POST 3 and POST 6. Correlations were used to assess whether improvement on transfer measures reflect training efficacy. A standard α-level of .05 was used for all analyses.

RESULTS

Baseline characteristics and pre-training performance

Figure 3 shows the participant flow in the study. Participants were recruited between 2013 and 2015 and testing was done from September 2014 to June 2015. Out of the 54 initially recruited participants, seven did not meet the inclusion criteria for SCD and were not randomized and seven withdrew before the PRE (Figure 3) and were thus excluded from the analysis. There was no further withdrawal among the 40 remaining participants (VR+, $n = 20$;

VR-, n = 20). The baseline characteristics of the participants who completed the intervention are presented below in table 1. The groups did not differ on any of the variables at baseline.

Figure 3. Flow chart of participants

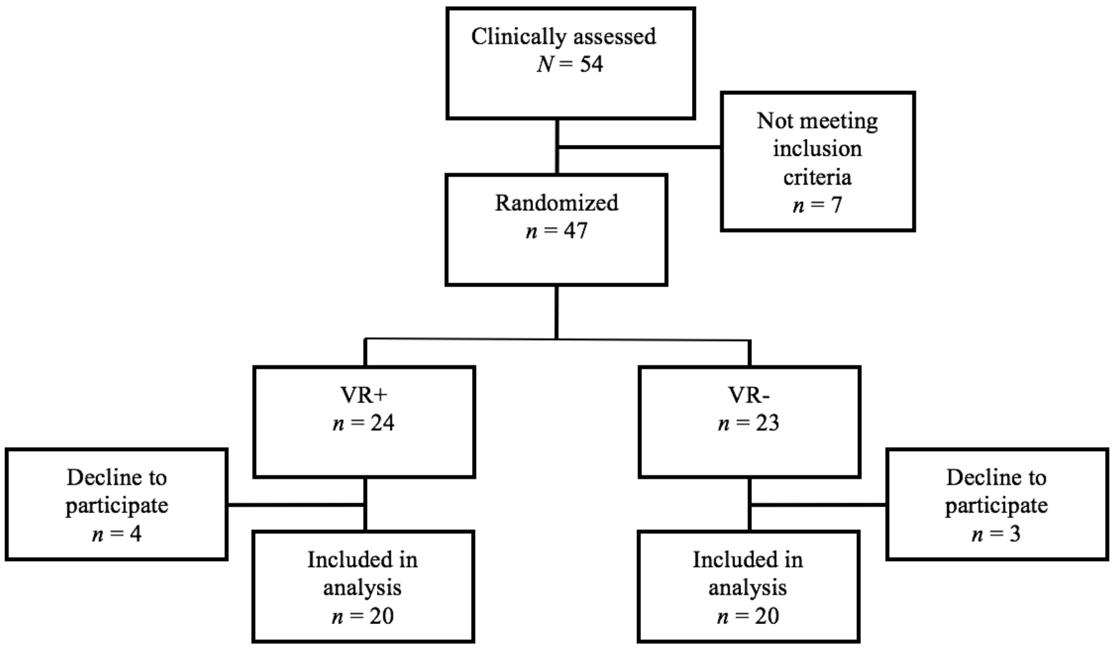

Table 1

Baseline characteristics of participants randomized to the VR+ and VR- training conditions

	VR+ (*n* = 20)	VR- (*n* = 20)
Gender (Women/Men)	16/4	17/3
Age	66.00 (7.67)	68.60 (7.27)
Education	15.30 (2.87)	14.70 (3.37)
ADL-PI (/30)	2.15 (2.83)	0.75 (1.48)
GDS (/15)	2.35 (3.79)	1.45 (1.76)
MoCA (/30)	27.80 (1.54)	27.50 (1.73)
Hachinski Scale (/18)	1.23 (0.28)	0.75 (0.17)
Charlson Comorbidity Index (/41)	0.55 (.76)	0.55 (.83)
Boston Naming Test (/15)	13.90 (1.17)	13.80 (1.28)
RL/RI delayed free recall (/16)	12.55 (1.93)	11.55 (1.36)
LM I (immediate recall) (/25)	15.30 (3.92)	14.70 (4.49)
LM I (delayed recall) (/25)	14.35 (4.40)	14.00 (3.23)
Stroop (time on third plate)	28.26(8.35)	28.84 (6.31)
Vocabulary (Scale Score, 1-19)	14.00 (2.20)	13.65 (2.41)

Note. ADL-PI = Activities of Daily Living-Prevention Instrument; GDS = Geriatric depression scale; RL/RI-16 = 16-item Free and Cued Recall; LMI = Logical Memory I subtest.

Measure of training efficacy (near content transfer)

The mean number of words correctly recalled in the two training conditions over the three testing phases is presented in Figure 4. A main effect of Phase is expected as the method of loci is expected to improve memory performance. The Condition x Phase ANOVA indicated a main effect of Phase, $F(2,37) = 12.55$, $p < .001$; $\eta^2_p = .25$. Paired comparisons indicated that performance increased from PRE to POST 3 ($p < .01$) and that there was no further improvement from POST 3 to POST 6. The Condition and Condition x Phase interaction was not significant.

Figure 4. Performance on the measure of training efficacy

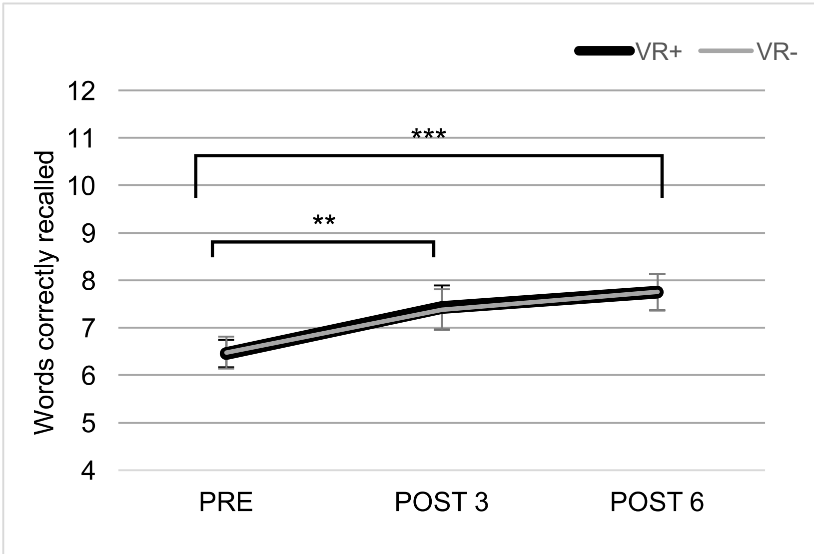

Figure 4. The mean of words correctly recalled on measure of training efficacy for the three testing phases in the VR+ (black) and VR- (gray) training conditions. Error bars represent standard error. *** $p < .01$ *** $p < .001$. Paired comparisons indicated a significant difference between PRE and POST 3, and between PRE and POST 6.*

Context transfer measures

The Virtual Shop[4] (near context tranfert). The mean number of objects correctly recalled in the virtual environment for the three testing phases and the two training conditions is presented in Figure 5. We hypothesized a greater performance increase in VR+ than in VR- which should result in a Condition x Phase interaction. The ANOVA indicated a Phase effect, $F(2,35) = 13.73$, $p < .001$; $\eta^2_p = .28$ but no effect of Condition or interaction. Paired

[4] Note that two participants (one from VR+, one from VR-) did not complete the Virtual Shop assessment due to cybersickness symptoms. Consequently, the following analyses were conducted on 38 participants.

comparisons revealed that the effect of Phase was due to a significant improvement from PRE to POST 3 ($p < .001$) with no further improvement from POST 3 to POST 6.

Figure 5. Performance in The Virtual Shop

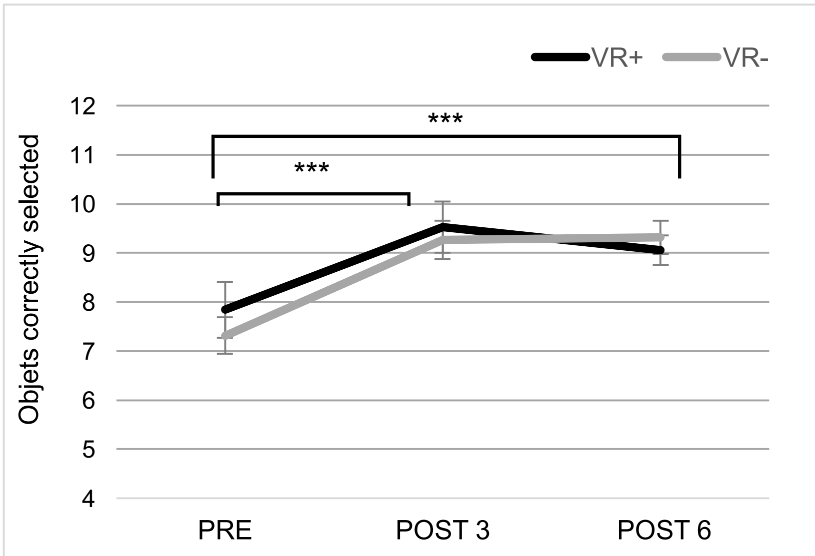

Figure 5. Correct recall in the Virtual Shop for the three testing phases in the VR+ (black) and VR- (gray) training conditions. ****p < .001, paired comparisons showed significant difference between PRE and POST 3, and between PRE and POST 6.*

The Virtual Car Ride[5] (far context transfert). The mean number of words correctly recalled over the three testing phases and the two training conditions are presented in Figure 6a. A Condition x Phase interaction was expected. The ANOVA indicated a main effect of Phase, $F(2,34) = 8.35$, $p < .01$; $\eta^2_p = .19$. but no Condition or interaction. Paired comparisons revealed that the effect of testing phase was due to a significant improvement from PRE to POST 3, $p < .05$, with no further improvement from POST 3 to POST 6. Figure 6b presents the accuracy performance for the road sign detection task. The ANOVA revealed no

[5] Note that three participants (two from VR+, one from VR-) did not complete the Virtual Car Ride assessment due to cybersickness symptoms. Consequently, the following analyses were conducted on 37 participants.

significant effect of Training condition, $F(2,34) = 0.05$, $p = .83$, Phase, $F(2,34) = 1.62$, $p = .21$, or interaction $F(2,34) = 0.51$, $p = .58$.

Figure 6. Performance in the Virtual Car Ride

a.

b.

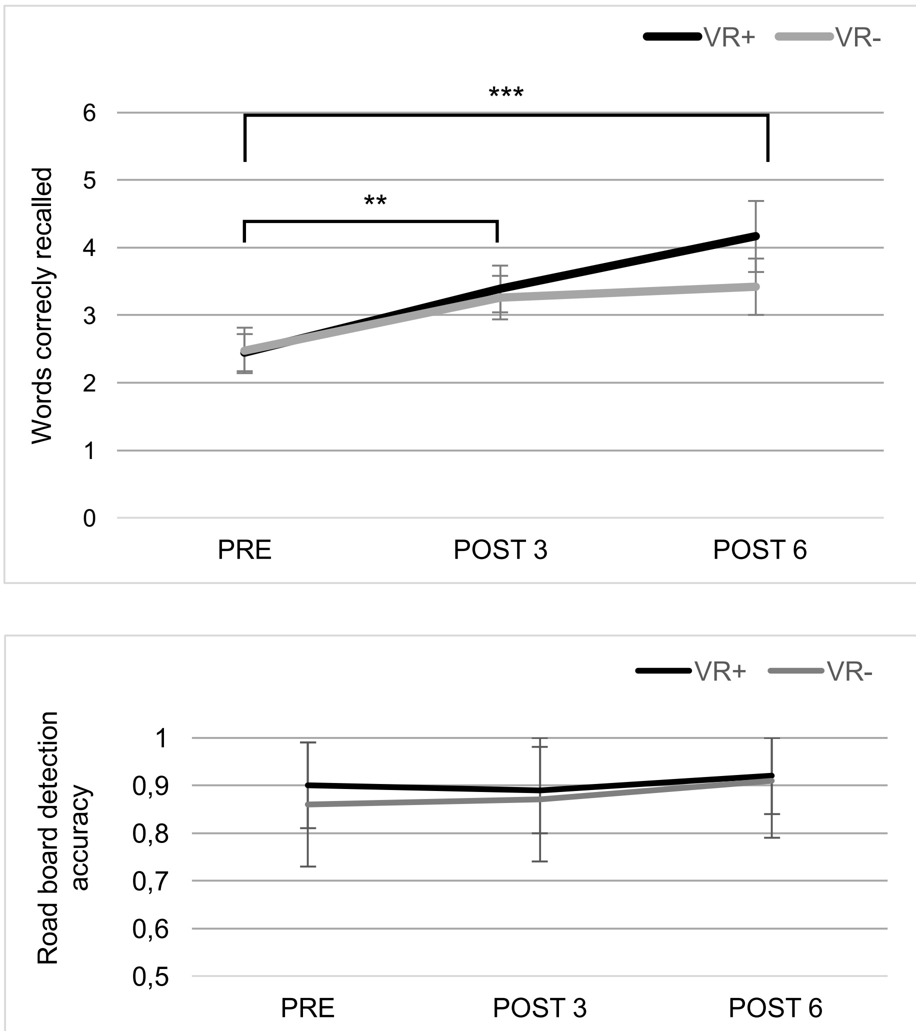

Figure 6. a. Correct recall in the Virtual Car Ride for the three testing phases in the VR+ (black) and VR- (gray) training conditions. *** p < .01 *** p < .001, paired comparisons showed significant difference between PRE and POST 3, and between PRE and POST 6.* b. Proportion of accuracy for the three testing phases for road board detection in the VR+ (black) and VR- (gray) training conditions.

The *MMQ questionnaire*[6]. Means and standard deviations for MMQ-Ability subscale are presented in Table 2. The ANOVA revealed no significant effect of Phase, $F(1,37) = 1.43$, $p = .24$, or interaction, $F(1,37) = 0.41$, $p = .53$. but there was a main effect of Training condition, $F(1,37) = 6.11$, $p < .05$, due to the VR+ group having more complaints than the VR- group overall.

Table 2

Mean scores MMQ-Ability Questionnaire in the VR+/VR- training conditions

	PRE		POST 6	
	VR+	VR-	VR+	VR-
MMQ Questionnaire	44.70 (10.14)	50.75 (14.48)	45.55 (10.41)	51.75 (15.04)

Relationship between training efficacy and context transfer effects

A significant correlation was found between improvement on word recall and improvement on the Virtual Car Ride ($r = 0.32$, $p < .05$). The positive correlation indicates that larger improvement on the efficacy measure is associated with larger improvement in the Virtual Car Ride. None of the other correlations are significant.

DISCUSSION

Our goals were to assess if VR can be used to measure real life transfer of strategic memory training, and whether providing practice in a VR environment that reproduced a real-life situation where the learned strategy can be applied increased efficacy and transfer. Older adults with memory complaints were randomized in two memory training conditions which do

[6] Note that one participant (from VR-) was excluded as he/she did not complete all questions from the questionnaire. Consequently, the following analyses were conducted on 39 participants.

(VR+) don't (VR-) include memory exercises in VR. They were assessed before training (PRE), after three (POST 3) and after six (POST 6) training sessions with one measure of training efficacy and three of *context transfer* (two VR tasks and one self-reported scale). Overall, results suggest that our strategic memory training is effective and that its benefits can be transferred from visual to auditory stimuli. Contexts transfer effects were also observed on VR tasks that are close to real-world situations following training, but not on self-reported everyday memory. However, enriching training with VR exercises that mimic a real-world situation doesn't increase transfer effects. Efficacy and context transfer effects were obtained after three training sessions and were not increased afterwards.

Training efficacy and content transfer

Prior to examining context transfer, it is important to ensure that training successfully increases memory performance in measures that are close to the trained task, as inefficient learning cannot be transferred. This was done by examining training effect on a word-recall task presented in the auditory modality. This represents near *content transfer* because we have changed the modality of presentation from visual to auditory, relative to the training. Participants showed a reliable pre-post training effect on this task, indicating near *content transfer*. Thus, training in the method of loci can be generalized to a task that modifies the input modality. This is important because verbal items that need to learned can be provided in a range of input types and modality. Finding transfer to the auditory modality is interesting since in everyday life, items that should be remembered are often presented in the auditory modality (for instance when you are talking on the phone, when a healthcare professional gives you instructions, etc.). Even though measuring near *content transfer* was not the focus of this study, the observation of a near transfer is nevertheless comforting to support the everyday usefulness of the technique. Note that our finding of a modality transfer is consistent with prior studies reporting near transfer effect on tasks that modify input modality following attentional training in older adults (Lussier, Gagnon, & Bherer, 2012; Bherer et al., 2008).

Context transfer

One innovative aspect of this study resides in the utilization of VR to objectively evaluate context transfer, with the assumption that VR is more likely to capture real-life transfer than self-rated questionnaires. Three measures were used to assess context transfer. A version of the Virtual Shop that was slightly different from the one used in the VR+ group, recalling words while multi-tasking in the Virtual Car Ride, and a self-report questionnaire measuring everyday memory capacity. We did not find transfer on the self-reported questionnaire, but the results indicate context transfer, that is better recall in the VR environments from PRE to POST 3, on both the Virtual Shop and Virtual Car Ride. Interestingly, the two VR context transfer tasks are different in terms of their proximities to the training conditions. The Virtual shop reproduces the shopping scenario used during training in both conditions, with similar input and response modalities. In that case, one might argue that this task measures near context transfer particularly for the participants randomized to the VR+ condition. In turn, the Virtual Car Ride places participants in a context which is very different from the conditions in training and for that reason, it provides clear evidence for context transfer. Interestingly, we found a positive correlation between the Virtual Car Ride and word recall improvements, which supports our interpretation that the pre-post improvement on that task reflects transfer rather than a mere practice effect. Overall, our findings indicate that the effect of memory training can generalize to contexts that are quite different from those that were trained, contrary to what was previously suggested (Melby-Lergag, Redick, & Hulme, 2016; Brehmer, Kalpouzos, Wenger & Lövdén, 2014; Zelinsky, 2009; Rebok et al., 2007; Kelly et al., 2014). These results are important regarding real life, where memory is solicited in a variety of situations that are different from training tasks and that also differ one from another. Transfer in a multi-tasking situation is also important, since learning or remembering information in real life must often be done while performing a concurrent task (for instance when you drive a car while remembering a route, when you have a conversation in a bus while watching the bus stops, etc.).

Importantly, no change was found following training on MMQ-memory ability's score and change on MMQ did not correlate with efficacy. This is unsurprising as lack of transfer on self-reported measures has been frequently reported in the literature (Ball et al., 2002; Belleville et al., 2018). The present observations are also like those of Bier, Ouellet and Belleville (2018). The authors reported better dual-task performance in a real-life scenario following a variable priority training in seniors, but no impact on a self-reported questionnaire.

Therefore, it appears that self-reported questionnaires might fail to appraise *context transfer* even when objective evidence has been found. There are many reasons that might explain the inability of self-reported questionnaires to reflect transfer. As mentioned above, responses on self-reported questionnaires are influenced by mood and metacognition. Specifically, it was shown that subjective memory in aging is generally more related to anxiety (Derouesné, Lacomblez, Thibault, & Leponcin, 1999) or personality traits (Barker, Prior, & Jones, 1995) than objective memory performance. Consequently, it may be difficult to change subjective memory performance with a cognitive intervention that doesn't focus on psychological symptoms. In this study, we recruited SCD individuals exhibiting worries about their memory, which could have created a negative bias in their memory self-evaluation. In addition, longitudinal studies have suggested that metacognition in aging tends to be stable over time (McDonald-Miszczak, Hertzog, & Hultsch, 1995; Weaver Cargin, Collie, Masters, & Maruff, 2008). In our study, SCD individuals were recruited specifically for their subjective memory complaint. Therefore, their perception having bad memory might be stable later regardless of the effects of the intervention that we made.

Our findings indicate that VR can be used as means to measure transfer, and that VR can provide more sensitive measures than self-reported questionnaires. In addition, VR assessments were previously shown to predict real-world performance (Renison, Ponsford, Testa, Richardson, & Brownfield, 2012; Allain et al., 2014), contrary to traditional experimental tasks (Chaytor & Schmitter-Edgecombe, 2003). This doesn't come as a surprise since experimental memory tasks are often word lists which remain very different than memorizing in challenging everyday situations (e.g., where you can be in dual-tasking, in noisy environment and/or in moving, etc.). Furthermore, it appears that VR cognitive assessments have the advantage of being more motivating than traditional cognitive tasks and generate a good sense of ‘‘presence’’, i.e. being there (Corriveau-Lecavalier et al., 2018), two variables associated with memory performance (Hess, Popham, Emery, & Elliott, 2012; Corriveau-Lecavalier et al., 2018).

The role of VR in increasing training efficacy and context transfer

One of our goals was to test if practicing the memory strategy in a complex VR environment would increase *context transfer*. Contrary to our expectations, the VR+ training group did not show better performance on the efficacy measure or better *context transfer* than the VR- training group. This is counter to the few studies showing that full VR memory training (Man et al., 2012) or cognitive intervention including VR exercises (Optale et al., 2010) resulted in better cognitive improvement than non-VR training. To reduce the risk of cybersickness symptoms, we provided relatively short practice sessions in the virtual environment contrary to Optale's and Man's study, both of which allocated 30 min to the VR experience. This could have reduced the likelihood of observing an effect due to VR training. Thus, insufficient training dosage might explain our failure to observe an impact of VR training on efficacy or transfer. One other possibility is that VR training exercises were not appropriate, i.e., not enough specific, complex or rich enough to impact cognition beyond the traditional method of loci learning. In sum, more research is needed to identify the optimal conditions to induce *context transfer* following VR training.

The effect of training dose

The design included three measurements to assess the effect of training dose on efficacy and transfer. In both cases, changes were found to occur from pre- to midway through training with no further improvement afterwards. Results were consistent, since this effect was found on all measures. This is similar to previous findings indicating that training duration was not associated with training gains in strategic training (for a meta-analysis, see Gross et al., 2012), while it was the case for those using repeated practice (for a meta-analysis, see Schwaighofer et al., 2015). Thus, the course of cognitive gains seems linear with passive repeated practice. By contrast, improvement in strategic learning might follow a non-linear pattern: performance may be optimized as soon as the strategy is mastered. One of our motivations to assess training dose was to ask whether the limited transfer reported by previous training studies could be accounted for by insufficient training dosage. The results that we obtained and the meta-analysis from Gross et al. suggests that this might not be the case, at least for studies using similar types of strategic training that were used here.

Interestingly, our results with dose effects indicates that efficacy and transfer effects can be observed following a relatively low dose of training on the method of loci. Therefore, short trainings can be enough to have a positive impact on everyday memory of older adults. This is important because clinical environments had often limited financial and human resources that make the implementation of long term intervention programs difficult. However, we cannot exclude that increasing training dose doesn't have short term impact, but that overlearning facilitates long term maintenance of transfer gains.

Limitations

It is important to address the some of the limitations of the study. First, we did not include a no-contact condition which makes the interpretation of our finding more complex because we cannot completely rule out that some of the effect comes from a mere test-retest effect. However, finding a positive correlation between change scores on measure of training efficacy and change scores on transfer suggests that this improvement is due to the efficient learning and use of method of loci. Furthermore, the present study did not examine the effect on maintenance of training and transfer gains. Lastly, the Virtual Shop and the Virtual Car Ride were constructed to be closer to real-life memory situations – and thus more ecologically valid – than traditional experimental tasks. Yet they remain experimental procedures in that the task is relatively confined in space and time, participants are instructed about the goals of the task and the encoding and retrieval phases are not entirely self-initiated. The VR tasks also require interaction with technological material (wearing an HDM, using remote or mouse, etc.), and the performance of older adults might be influenced by their degree of familiarity with new technologies (Lopez & Cleeremans, 2016; Iverson, Brooks, Ashton, Johnson, & Gualtieri, 2009). Note however, that we did found evidence from earlier work that VR tasks are feasible and valid in older adults (Corriveau-Lecavalier et al., 2018; Ouellet et al., 2018).

Conclusion

In summary, our findings indicate that providing a low dose of strategic-based memory training to older adults with a subjective decline leads to memory increase and transfer in situations that are close to real life context. VR can be used to measure transfer effects in situations that are close to daily life, and it was found to be sensitive to training and to better reflect transfer than a self-reported scale. However, the VR training add-on that was used did not increase efficacy or transfer which results from a classical face-to-face training intervention. Overall, memory training based on strategies such as the method of loci is a promising non-pharmacological approach that can help seniors with memory complaints cope with the everyday memory difficulties. Furthermore, as these individuals are susceptible to be in a prodromal phase of AD (Jessen et al., 2014), providing memory training might delay the impact of the disease on functional autonomy.

CONFLIT OF INTEREST

The authors declare no conflict of interest.

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REFERENCES

Akhtar, S., Moulin, C. J., & Bowie, P. C. (2006). Are people with mild cognitive impairment aware of the benefits of errorless learning? *Neuropsychological Rehabilitation*, *16*(3), 329–346. doi:10.1080/0960500176674

Allain, P., Foloppe, D. A., Besnard, J., Yamaguchi, T., Etcharry–Bouyx, F., Le Gall, D., . . . Richard, P. (2014). Detecting everyday action deficits in Alzheimer's disease using a nonimmersive virtual reality kitchen. *Journal of the International Neuropsychological Society, 20*(05), 468–477. doi:10.1017/S1355617714000344

Austin, K. (2009) Multimedia learning: Cognitive individual differences and display design techniques predict transfer learning with multimedia learning modules. *Computers & Education, 53*(4), 1339–1354. doi:10.1016/j.compedu.2009.06.017

Ball, K., Berch, D. B., Helmers, K. F., Jobe, J. B., Leveck, M. D., Marsiske, M., . . . Unverzagt, F. W. (2002). Effects of cognitive training interventions with older adults: A randomized controlled trial. *The Journal of the American Medical Association*, *288*(18), 2271–2281. doi:10.1001/jama.288.18.2271

Barker, A., Prior, J., & Jones, R. (1995). Memory complaint in attenders at a self-referral memory clinic: The role of cognitive factors, affective symptoms and personality. *International Journal of Geriatric Psychiatry*, *10*(9), 777–781. doi:10.1002/gps.930100908

Belleville, S., Boller, B., & del Val, L. P. (2016). Cognitive Training in Mild Cognitive Impairment. In T. Strobach and J. Karbach (Eds.), *Cognitive Training* (pp. 187-197). Springer, Cham.

Belleville, S., Clément, F., Mellah, S., Gilbert, B., Fontaine, F., & Gauthier, S. (2011). Training-related brain plasticity in subjects at risk of developing Alzheimer's disease. *Brain, 134*(6), 1623–1634. doi:10.1093/brain/awr037

Belleville, S., Gilbert, B., Fontaine, F., Gagnon, L., Ménard, É., & Gauthier, S. (2006). Improvement of episodic memory in persons with mild cognitive impairment and healthy older adults: Evidence from a cognitive intervention program. *Dementia and Geriatric Cognitive Disorders, 22*(5–6), 486–499. doi:10.1159/000096316

Belleville, S., Hudon, C., Bier, N., Brodeur, C., Gilbert, B., Grenier, S., . . . Gauthier, S. (2018). MEMO+: Efficacy, durability and effect of cognitive training and psychosocial intervention in individuals with mild cognitive impairment. *Journal of the American Geriatrics Society*, 1–9. doi:10.1111/jgs.15192

Bennett, D. A., Wilson, R. S., Schneider, J. A., Evans, D. A., Beckett, L. A., Aggarwal, N. T., . . . Bach, J. (2002). Natural history of mild cognitive impairment in older persons. *Neurology, 59*(2), 198–205. doi:10.1212/WNL.59.2.198

Bherer, L., Kramer, A. F., Peterson, M. S., Colcombe, S., Erickson, K., & Becic, E. (2008). Transfer effects in task-set cost and dual-task cost after dual-task training in older and younger adults: Further evidence for cognitive plasticity in attentional control in late adulthood. *Experimental Aging Research, 34*(3), 188–219. doi:10.1080/03610730802070068

Brehmer, Y., Kalpouzos, G., Wenger, E., & Lövdén, M. (2014). Plasticity of brain and cognition in older adults. *Psychological Research*, *78*(6), 790–802. doi:10.1007/s00426–014–0587–z

Brooks, B. M. (1999). Route learning in a case of amnesia: A preliminary investigation into the efficacy of training in a virtual environment. *Neuropsychological Rehabilitation, 9*(1), 63–76. doi:10.1080/713755589

Brum, P. S., Forlenza, O. V., & Yassuda, M. S. (2009). Cognitive training in older adults with mild cognitive impairment: Impact on cognitive and functional performance. *Dementia & Neuropsychologia, 3*(2), 124–131. doi:10.1590/S1980-57642009DN30200010

Butterfield, E. C., & Nelson, G. D. (1991). Promoting positive transfer of different types. *Cognition and Instruction*, *8*(1), 69–102. doi:10.1207/s1532690xci0801_3

Chandler, M. J., Parks, A. C., Marsiske, M., Rotblatt, L. J., & Smith, G. E. (2016). Everyday impact of cognitive interventions in mild cognitive impairment: A systematic review and meta-analysis. *Neuropsychology Review, 26*(3), 225–251. doi:10.1007/s11065-016-9330-4

Charlson, M. E., Pompei, P., Ales, K. L., & MacKenzie, C. R. (1987). A new method of classifying prognostic comorbidity in longitudinal studies: Development and validation. *Journal of Chronic Diseases*, *40*(5), 373–383. doi:10.1016/0021-9681(87)90171-8

Chaytor, N., & Schmitter-Edgecombe, M. (2003). The ecological validity of neuropsychological tests: A review of the literature on everyday cognitive skills. *Neuropsychology Review, 13*(4), 181–197. doi:10.1023/B:NERV.0000009483.91468.fb

Corriveau–Lecavalier, N., Ouellet, É., Boller, B., & Belleville, S. (2018). Use of immersive virtual reality to assess episodic memory: A validation study in older adults. Manuscript submitted for publication.

Cromby, J., Standen, P., Newman, J., & Tasker, H. (1996). Successful transfer to the real world of skills practised in a virtual environment by students with severe learning difficulties. In P. Sharkey (Ed.), *Proceedings 1st European Conference on Disability, Virtual Reality, and Associated Technologies* (pp. 103–107). Maidenhead, UK: The University of Reading.

Cushman, L. A., Stein, K., & Duffy, C. J. (2008). Detecting navigational deficits in cognitive aging and Alzheimer disease using virtual reality. *Neurology, 71*(12), 888–895. doi:10. 1212/01.wnl.0000326262.67613.fe

Derouesné, C., Lacomblez, L., Thibault, S., & Leponcin, M. (1999). Memory complaints in young and elderly subjects. *International Journal of Geriatric Psychiatry*, *14*(4), 291–301. doi:10.1002/(SICI)1099-1166(199904)14:4<291::AID GPS902>3.0.CO;2-7

Engvig, A., Fjell, A. M., Westlye, L. T., Moberget, T., Sundseth, Ø., Larsen, V. A., & Walhovd, K. B. (2010). Effects of memory training on cortical thickness in the elderly. *Neuroimage*, *52*(4), 1667–1676. doi:10.1016/j.neuroimage.2010.05.041

Engvig, A., Fjell, A. M., Westlye, L. T., Skaane, N. V., Dale, A. M., Holland, D., . . . Walhovd, K. B. (2014). Effects of cognitive training on gray matter volumes in memory clinic patients with subjective memory impairment. *Journal of Alzheimer's Disease*, *41*(3), 779–791. doi:10.3233/JAD-131889

Engvig, A., Fjell, A. M., Westlye, L. T., Skaane, N. V., Sundseth, Ø., & Walhovd, K. B. (2012). Hippocampal subfield volumes correlate with memory training benefit in subjective memory impairment. *NeuroImage, 61*(1), 188–194. doi:10.1016/j.neuroimage.2012.02.072

Fort, I., Adoul, L., Holl, D., Kaddour, J., & Gana K. (2004). Psychometric properties of the French version of the Multifactorial Memory Questionnaire for adults and the elderly. *Canadian Journal on Aging, 23*(4), 347–57. doi:10.1353/cja.2005.0020

Galasko, D., Bennett, D. A., Sano, M., Marson, D., Kaye, J., & Edland, S. D. (2006). ADCS Prevention Instrument Project: Assessment of instrumental activities of daily living for community–dwelling elderly individuals in dementia prevention clinical trials. *Alzheimer Disease & Associated Disorders*, *20*, S152–S169. doi:10.1097/01.wad.0000213873.25053.2b

Gilbert, B., Fontaine, S. F., Belleville, S., Gagnon, L., & Ménard, E. (2008). Programme d'intervention cognitive pour les aînés: programme MEMO, Montréal.

Gonneaud, J., Piolino, P., Lecouvey, G., Madeleine, S., Orriols, E., Fleury, P., . . . Desgranges, B. (2012). Assessing prospective memory in young healthy adults using virtual reality. In P. Sharkey, P. and E. Klinger, (Eds.), *Proceedings of the 9th International Conference on Disability, Virtual Reality, and Associated Technologies* (pp. 211–218), Laval, France: The University of Reading.

Gould, N. F., Holmes, M. K., Fantie, B. D., Luckenbaugh, D. A., Pine, D. S., Gould, T. D., . . . Zarate Jr, C. A. (2007). Performance on a virtual reality spatial memory navigation task in depressed patients. *American Journal of Psychiatry, 164*(3), 516–519. doi:10.1176/appi.ajp.164.3.516

Hachinski, V. C., Iliff, L. D., Zilhka, E., Du Boulay, G. H., McAllister, V. L., Marshall, J., . . . Symon, L. (1975). Cerebral blood flow in dementia. *Archives of Neurology*, *32*(9), 632–637. doi:10.1001/archneur.1975.00490510088009

Hampstead, B. M., Sathian, K., Moore, A. B., Nalisnick, C., & Stringer, A. Y. (2008). Explicit memory training leads to improved memory for face–name pairs in patients with mild cognitive impairment: Results of a pilot investigation. *Journal of the International Neuropsychological Society, 14*(05), 883–889. doi:10.1017/S1355617708081009

Hess, T. M., Popham, L. E., Emery, L., & Elliott, T. (2012). Mood, motivation, and misinformation: Aging and affective state influences on memory. *Aging, Neuropsychology, and Cognition*, *19*(1-2), 13–34. doi:10.1080/13825585.2011.622740

Jebara, N., Orriols, E., Zaoui, M., Berthoz, A., & Piolino, P. (2014). Effects of enactment in episodic memory: A pilot virtual reality study with young and elderly adults. *Frontiers in Aging Neuroscience, 6*, 1–16. doi:10.3389/fnagi.2014.00338

Jessen, F., Amariglio, R. E., Van Boxtel, M., Breteler, M., Ceccaldi, M., Chételat, G., . . . Glodzik, L. (2014). A conceptual framework for research on subjective cognitive decline in preclinical Alzheimer's disease. *Alzheimer's & Dementia, 10*(6), 844–852. doi:10.1016/j.jalz.2014.01.001

Jiang, C.-F., & Li, Y.-S. (2007). *Virtual hospital–a computer–aided platform to evaluate the sense of direction.* Paper presented at the Engineering in Medicine and Biology Society, EMBS 2007. 29th Annual International Conference of the IEEE, Lyon, France.

Jobe, J. B., Smith, D. M., Ball, K., Tennstedt, S. L., Marsiske, M., Willis, S. L., . . . Kleinman, K. (2001). ACTIVE: A cognitive intervention trial to promote independence in older adults. *Controlled Clinical Trials*, *22*(4), 453–479. doi:10.1016/S0197-2456(01)00139-8

Kaplan, E. F., Goodglass, H., & Weintraub, S. (1983). Boston Naming Test (2nd edition). *Philadelphia: Lea & Febiger*.

Kelly, M. E., Loughrey, D., Lawlor, B. A., Robertson, I. H., Walsh, C., & Brennan, S. (2014). The impact of cognitive training and mental stimulation on cognitive and everyday functioning of healthy older adults: A systematic review and meta–analysis. *Ageing Research Reviews*, *15*, 28–43. doi:10.1016/j.arr.2014.02.004

Kinsella, G. J., Mullaly, E., Rand, E., Ong, B., Burton, C., Price, S., . . . Storey, E. (2009). Early intervention for mild cognitive impairment: A randomised controlled trial. Journal of Neurology. *Neurosurgery & Psychiatry, 80*(7), 730–736. doi:10.1136/jnnp.2008.148346

Kurz, A., Pohl, C., Ramsenthaler, M., & Sorg, C. (2009). Cognitive rehabilitation in patients with mild cognitive impairment. *International Journal of Geriatric Psychiatry, 24*(2), 163–168. doi:10.1002/gps.2086

Lampit, A., Hallock, H., & Valenzuela, M. (2014). Computerized cognitive training in cognitively healthy older adults: A systematic review and meta-analysis of effect modifiers. *PLoS Med*, *11*(11), e1001756. doi:10.1371/journal.pmed.1001756

Lea, G. (1975). Chronometric analysis of the method of loci. *Journal of Experimental Psychology: Human Perception and Performance*, *1*(2), 95. doi:10.1037/0096–1523.1.2.95

Lim, M. H., Liu, K. P., Cheung, G. S., Kuo, M. C., Li, R., & Tong, C. Y. (2012). Effectiveness of a multifaceted cognitive training programme for people with mild cognitive impairment: A one-group pre- and posttest design. *Hong Kong Journal of Occupational Therapy, 22*(1), 3–8. doi:10.1016/j.hkjot.2012.04.002

Lobato, J. (2006). Alternative perspectives on the transfer of learning: History, issues, and challenges for future research. *The Journal of the Learning Sciences*, *15*(4), 431–449. doi:10.1207/s15327809jls15041

Lussier, M., Gagnon, C., & Bherer, L. (2012). An investigation of response and stimulus modality transfer effects after dual-task training in younger and older. *Frontiers in Human Neuroscience, 6*(129), 1–11. doi:10.3389/fnhum.2012.00129

Lustig, C., & Flegal, K. E. (2008). Targeting latent function: Encouraging effective encoding for successful memory training and transfer. *Psychology and Aging, 23*(4), 754–764. doi:10.1037/a0014295

Man, D. W., Chung, J. C., & Lee, G. Y. (2012). Evaluation of a virtual reality-based memory training programme for Hong Kong Chinese older adults with questionable dementia: A pilot study. *International Journal of Geriatric Psychiatry, 27*(5), 513–520. doi:10.1177/1545968309353328

Max Planck Institute for Human Development and Stanford Center on Longevity (accessed 2016). "A Consensus on the Brain Training Industry from the Scientific Community," http ://longevity3.stanford.edu/blog/2014/10/15/the–consensus–on–the–brain–training–industry–from–the–scientific–community/

Mayer, R. E., & Wittrock, M. C. (1996). Problem-solving transfer. In D. C. Berliner & R. C. Calfee (Eds.), *Handbook of Educational Psychology* (pp. 47–62). New York, NY: MacMillan Library Reference.

McDonald-Miszczak, L., Hertzog, C., & Hultsch, D. F. (1995). Stability and accuracy of metamemory in adulthood and aging: A longitudinal analysis. *Psychology and Aging*, *10*(4), 553–564. doi:10.1037/0882-7974.10.4.553

Melby–Lervåg, M., Redick, T. S., & Hulme, C. (2016). Working memory training does not improve performance on measures of intelligence or other measures of "far transfer" evidence from a meta–analytic review. *Perspectives on Psychological Science*, *11*(4), 512–534. doi:10.1177/1745691616635612

Moher, D., Hopewell, S., Schulz, K. F., Montori, V., Gøtzsche, P. C., Devereaux, P. J., . . . Altman, D. G. (2010). CONSORT 2010 explanation and elaboration: Updated guidelines for reporting parallel group randomised trials. *BMJ*, *340*, c869. doi:10.1136/bmj.c869

Moroni, C. & Bayard, S. (2009). Processus d'inhibition: quelle est leur valeur évolutive après 50 ans? *Psychologie & Neuropsychiatrie du Vieillissement, 7*, 121–129.

doi:10.1684/pnv.2009.0155

Nasreddine, Z. S., Phillips, N. A., Bédirian, V., Charbonneau, S., Whitehead, V., Collin, I., . . . Chertkow, H. (2005). The Montreal Cognitive Assessment, MoCA: A brief screening tool for mild cognitive impairment. *Journal of the American Geriatrics Society, 53*(4), 695–699. doi:10.1111/j.1532–5415.2005.53221.x

Noack, H., Lövdén, M., Schmiedek, F., & Lindenberger, U. (2009). Cognitive plasticity in adulthood and old age: Gauging the generality of cognitive intervention effects. *Restorative Neurology and Neuroscience*, *27*(5), 435–453. doi:10.3233/RNN-2009-0496.

Olchik, M. R., Farina, J., Steibel, N., Teixeira, A. R., & Yassuda, M. S. (2013). Memory training (MT) in mild cognitive impairment (MCI) generates change in cognitive performance. *Archives of Gerontology and Geriatrics*, *56*(3), 442–447. doi:10.1016/j.archger.2012.11.007

Optale, G., Urgesi, C., Busato, V., Marin, S., Piron, L., Priftis, K., . . . Bordin, A. (2010). Controlling memory impairment in elderly adults using virtual reality memory training: A randomized controlled pilot study. *Neurorehabilitation and Neural Repair*, *24*(4), 348–357. doi:10.1177/1545968309353328

Ouellet, É., Boller, B., Corriveau–Lecavalier, N., Cloutier, S. & Belleville S. (2018). The Virtual Shop: A new immersive virtual reality environment and scenario for the assessment of everyday memory. *Journal of Neuroscience Methods.* doi:10.1016/j.jneumeth.2018.03.010

Owsley, C., Sloane, M., McGwin Jr, G., & Ball, K. (2002). Timed instrumental activities of daily living tasks: Relationship to cognitive function and everyday performance assessments in older adults. *Gerontology, 48*(4), 254–265. doi:10.1159/000058360

Parsons, T. D. (2015). Ecological validity in virtual reality-based neuropsychological assessment. In M. Khosrow-Pour (Ed.), *Encyclopedia of Information Science and*

Technology (3th edition, pp. 1006-1015). IGI Global. doi:10.4018/978-1-4666-5888-2.ch095

Perkins, D. N., & Salomon, G. (1992). Transfer of learning. *International Encyclopedia of Education*, *2*, 6452–6457.

Plancher, G., Gyselinck, V., Nicolas, S., & Piolino, P. (2010). Age effect on components of episodic memory and feature binding: A virtual reality study. *Neuropsychology, 24*(3), 379–390. doi:10.1037/a0018680

Rapp, S., Brenes, G., & Marsh, A. (2002). Memory enhancement training for older adults with mild cognitive impairment: A preliminary study. *Aging and Mental Health, 6*(1), 5–11. doi:10.1080/13607860120101077

Rebok, G. W., Carlson, M. C., & Langbaum, J. B. (2007). Training and maintaining memory abilities in healthy older adults: Traditional and novel approaches. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences, 62*(Special Issue 1), 53–61. doi:10.1093/geronb/62.special_issue_1.53

Renison, B., Ponsford, J., Testa, R., Richardson, B., & Brownfield, K. (2012). The ecological and construct validity of a newly developed measure of executive function: The Virtual Library Task. *Journal of the International Neuropsychological Society, 18*(03), 440–450. doi:10.1017/S1355617711001883

Rizzo, A. A., Schultheis, M., Kerns, K. A., & Mateer, C. (2004). Analysis of assets for virtual reality applications in neuropsychology. *Neuropsychological Rehabilitation, 14*(1–2), 207–239. doi:10.1080/09602010343000183

Rose, F. D., Brooks, B. M., & Rizzo, A. A. (2005). Virtual reality in brain damage rehabilitation: Review. *CyberPsychology & Behavior, 8*(3), 241–262. doi:10.1089/cpb.2005.8.241

Salomon, G., & Perkins, D. N. (1989). Rocky roads to transfer: Rethinking mechanism of a neglected phenomenon. *Educational Psychologist*, *24*(2), 113–142. doi:10.1207/s15326985ep24021

Saposnik, G., & Levin, M. (2011). Virtual reality in stroke rehabilitation a meta-analysis and implications for clinicians. *Stroke, 42*(5), 1380–1386. doi:10.1161/STROKEAHA.110.605451

Schwaighofer, M., Fischer, F., & Bühner, M. (2015). Does working memory training transfer? A meta-analysis including training conditions as moderators. *Educational Psychologist*, *50*(2), 138–166. doi:10.1080/00461520.2015.1036274

Shuchat, J., Ouellet, É., Moffat, N., & Belleville, S. (2012). Opportunities for virtual reality in cognitive training with persons with mild cognitive impairment or Alzheimer's disease. *Non-Pharmacological Therapies in Dementia, 3*(1), 35–54.

Simons, D. J., Boot, W. R., Charness, N., Gathercole, S. E., Chabris, C. F., Hambrick, D. Z., & Stine–Morrow, E. A. (2016). Do "brain–training" programs work? *Psychological Science in the Public Interest*, *17*(3), 103–186. doi:10.1177/1529100616661983

Sorita, E., N'Kaoua, B., Larrue, F., Criquillon, J., Simion, A., Sauzéon, H., . . . Mazaux, J.-M. (2013). Do patients with traumatic brain injury learn a route in the same way in real and virtual environments? *Disability and rehabilitation, 35*(16), 1371–1379. doi:10.3109/09638288.2012.738761

Tremblay, M. P., Potvin, O., Belleville, S., Bier, N., Gagnon, L., Blanchet, S., . . . Hudon, C. (2016). The Victoria Stroop test: Normative data in Quebec–French adults and elderly. *Archives of Clinical Neuropsychology, 31*(8), 926–933. doi:10.1093/arclin/acw029

Troyer, A. K., Leach, L., & Strauss, E. (2006). Aging and response inhibition: Normative data for the Victoria Stroop Test. *Aging, Neuropsychology, and Cognition*, *13*(1), 20–35. doi:10.1080/138255890968187

Troyer, A. K., Murphy, K. J., Anderson, N. D., Hayman–Abello, B. A., Craik, F. I. M., & Moscovitch, M. (2008). Object and associative memory in amnestic mild cognitive impairment: Performance on standardized memory tests. *Neuropsychology, 22*(1), 10–16. doi:10.1037/0894–4105.22.1.10

Troyer, A. K., & Rich, J. B. (2002). Psychometric properties of a new metamemory questionnaire for older adults. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences, 57*(1), 19–27. doi:10.1093/geronb/57.1.P19

Van der Linden, M., Coyette, F., Poitrenaud, J., Kalafat, M., Calacis, F., Wyns, C., . . . et les membres du GREMEM (2004). L'épreuve de rappel libre/rappel indicé à 16 items (RL/RI-16). In M. Van der Liden, S. Adam, A. Agniel, C. Baisset Mouly, et al. (Eds.), *L'évaluation des troubles de la mémoire : Présentation de quatre tests de mémoire épisodique (avec leur étalonnage).* Marseille, France : Solal.

Verhaeghen, P., & Marcoen, A. (1996). On the mechanisms of plasticity in young and older adults after instruction in the method of loci: Evidence for an amplification model. *Psychology and Aging*, *11*(1), 164–178. doi:10.1037/0882-7974.11.1.164

Waller, D., Knapp, D., & Hunt, E. (2001). Spatial representations of virtual mazes: The role of visual fidelity and individual differences. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 43*(1), 147–158. doi:10.1518/001872001775992561

Wallet, G., Sauzéon, H., Larrue, F., & N'Kaoua, B. (2013). Virtual/real transfer in a large–scale environment: Impact of active navigation as a function of the viewpoint displacement effect and recall tasks. *Advances in Human-Computer Interaction, 2013* (Article No. 8), 1–7. doi:10.1155/2013/879563

Wallet, G., Sauzéon, H., Rodrigues, J., & N'Kaoua, B. (2009). Transfer of spatial knowledge from a virtual environment to reality: Impact of route complexity and subject's strategy on the exploration mode. *Journal of Virtual Reality and Broadcasting, 6*(4), 572–574. doi:10.20385/1860-2037/6.2009.4

Weaver Cargin, J., Collie, A., Masters, C., & Maruff, P. (2008). The nature of cognitive complaints in healthy older adults with and without objective memory decline. *Journal of Clinical and Experimental Neuropsychology, 30*(2), 245–257. doi:10.1080/13803390701377829

Wechsler, D. (1997). *Wechsler Memory Scale–Third Edition.* San Antonio, TX: The Psychological Corporation.

Wechsler, D. (2008). *Wechsler Adult Intelligence Scale–Fourth Edition*. San Antonio, TX: The Psychological Corporation.

Widmann, C. N., Beinhoff, U., & Riepe, M. W. (2012). Everyday memory deficits in very mild Alzheimer's disease. *Neurobiology of aging, 33*(2), 297–303. doi:10.1016/j.neurobiolaging.2010.03.012

Willis, S. L. & Belleville, S. (2016). Cognitive training in later adulthood. In K. W. Shaie and S. L. Willis (Eds.). *Handbook of the psychology of aging* (8th edition, pp. 219–243). London, UK: Elsevier.

Willis, S. L., Tennstedt, S. L., Marsiske, M., Ball, K., Elias, J., Koepke, K. M., . . . Wright, E. (2006). Long-term effects of cognitive training on everyday functional outcomes in older adults. *The Journal of the American Medical Association, 296*(23), 2805–2814. doi:10.1001/jama.296.23.2805

Yesavage, J. A., & Rose, T. L. (1983). Concentration and mnemonic training in elderly subjects with memory complaints: A study of combined therapy and order effects. *Psychiatry Research*, *9*(2), 157–167. doi:10.1016/0165–1781(83)90037–9

Yip, B., & Man, D. (2013). Virtual reality–based prospective memory training program for people with acquired brain injury. *Neurorehabilitation, 32*(1), 103–115. doi:10.3233/NRE–130827

Zelinski, E. M. (2009). Far transfer in cognitive training of older adults. *Restorative Neurology and Neuroscience*, *27*(5), 455–471. doi:10.3233/RNN–2009–0495

Zhang, L., Abreu, B. C., Seale, G. S., Masel, B., Christiansen, C. H., & Ottenbacher, K. J. (2003). A virtual reality environment for evaluation of a daily living skill in brain injury rehabilitation: reliability and validity. *Archives of Physical Medicine and Rehabilitation, 84*(8), 1118–1124. doi:10.1016/S0003–9993(03)00203–X

Chapitre IV

Article 3

Article 3

Training senior adults to memorize with irrelevant noise: A proof of concept study

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ABSTRACT

Memorizing in noisy environments is challenging, particularly for older adults. This randomized controlled study assessed if memory training improves the ability to memorize under irrelevant background speech, and whether combining attentional training to memory training increases this effect. Fifty-seven older adults with memory complaint were recruited. They were randomly assigned to a *Memory+Attention* or *Memory+Memory* group. Both groups learned and practiced the method of loci over 6 training sessions. However, the *Memory+Attention* group had auditory attention training added to memory training after the fourth session. Auditory training involved asking participants to perform the memory task in the presence of irrelevant verbal noise. The effect of training was measured with how much they could memorize and recall words of a list. This exercise was completed in silent and noisy conditions prior to training (PRE1), after session 3 (PRE2) and after session 6 (POST). Results indicated that both groups improved their word recall task following training, confirming the efficacy of method of loci to improve verbal memory. As expected, lower recall was found in noisy than in silent conditions at PRE1. This was also the case with PRE2, but the same results did not appear at POST. None of these effects interacted with the training condition. Thus, older adults can benefit from the method of loci to increase their ability to memorize words. Adding auditory attentional training does not improve the memory gain obtained from the training, but providing more practice is found to eliminate the detrimental effect of noise on memory.

INTRODUCTION

Unlike common conditions in typical cognitive experiments and during neuropsychological clinical testing, memorizing in everyday life is often done accompanied by distracting noise. Memorizing in noisy conditions might pose challenges for elderly people, as aging is associated with a decline in the ability to suppress task-irrelevant distracting information (Hasher & Zacks, 1988; Wais & Gazzaley, 2014; Anderson, Craik, & Navel-Benjamin, 1998). Unsurprisingly, one of the most frequent subjective complaints expressed by seniors concerns difficulties in learning or remembering information under attentionally demanding conditions, such as those encountered in noisy environments (Langlois &

Belleville, 2014). A large number of studies have shown that irrelevant speech noise interferes with short term serial recall (Colle & Welsh, 1976; Salamé & Baddeley, 1987; Miles, Jones, & Madden, 1991; Rouleau & Belleville, 1996; Van Gerven, Meijer, Vermeeren, Vuurman, & Jolles, 2007), with the ability to understand speech (Wiley et al., 1998; Tun, 1998; Pronk et al., 2013), and with verbal episodic memory (Lecompte, 1994; Knez & Hygge, 2002; Hygge, Boman, & Enmarker, 2003; Enmarker, 2004; Boman, 2004). The disruptive effect of noise is particularly detrimental to older adults when tested with episodic memory tasks (Tun, O'kane & Wingfield, 2002; Bell, Buchner, & Mund 2008; Meijer, De Groot, Van Boxtel, Van Gerven, & Jolles, 2006), which is problematic, since memorizing is often done in noisy environments. Strategic memory training is found to improve memory in older adults but it has only been tested in silent, not noisy, environments (Gross et al., 2012; Willis & Belleville, 2016; Belleville et al., 2006; Belleville et al., 2011; Belleville et al., 2018; Engvig et al., 2012). Furthermore, combining auditory attention training with memory training has the potential to improve the ability to memorize in noisy conditions, which may be useful for everyday life.

Memory training traditionally relies on teaching mnemonic strategies. Among them, the method of loci has been used extensively with the elderly (Verhaeghen, Marcoen, & Goossens, 1992; Willis & Belleville, 2016; Verhaeghen, 2016). This strategy is based on the creation of interactive associations between items to be remembered, and a sequence of loci from a familiar environment. At retrieval, each locus is mentally visited in serial order to extract the interactive images from which the original word is derived from (Bower, 1970). Many studies have shown that the method of loci improves word recall in older adults when tested in quiet conditions (Rose & Yesavage, 1983; Robertson-Tchabo, Hausman & Arenberg, 1976; Nyberg et al., 2003; Belleville et al., 2006; Ball et al., 2002; Engvig et al., 2012; Stigsdotter & Bäckman, 1989).

Adaptive auditory attention training can be used to complement the method of loci, and further improve older adult's performance in noisy environments. Previous studies have shown that divided attention in older adults can be improved with training (Kramer, Larish, & Strayer, 1995; Bherer et al., 2008; Gagnon & Belleville, 2012; Bier, de Boysson, & Belleville, 2014). However, none of these have trained selective auditory attention. A few studies assessed the effect of selective attention training in younger (van't Hooft et al., 2005; van't

Hooft et al., 2007; Kerns, MacSween, Vander Wekken, & Gruppuso, 2010) and older adults (Willis et al., 1983; Wilkinson, & Yang, 2012; 2015), but they most often focused on visual attention. To our knowledge, only one study assessed the effect of selective attention training with auditory distractors in older adults (Mozolic, Long, Morgan, Rawley-Payne & Laurienti, 2011). In that study, participants completed visual exercises (detection, identification, classification or sequencing of letters, words or numbers) in the presence of irrelevant auditory noise. The results indicated improved ability to complete the visual attention tasks in the presence of auditory distractors.

Given that seniors have difficulties memorizing with background noise interference, training their memory might increase their ability to memorize certain things under in noisy environments. Furthermore, this may be optimized by combining memorization with selective attention training using auditory distractors. The objective of the study was to assess whether training with the method of loci increases the older adult's ability to memorize in the presence of irrelevant background speech and reduces the detrimental effect of speech noise on their memory. It also tested whether combining adaptive auditory training and method of loci training would further reduce the detrimental effect of speech noise on memory. Participants were randomly assigned to a *Memory+Attention* or *Memory+Memory* condition. All participants were first trained with the method of loci, then they practiced it with attentional auditory training (*Memory+Attention*) or without attentional auditory training *(Memory+Memory*), respective to what group they were in. The difficulty of the attentional training was incremental, which was based on the work from Jones and Macken (1995) showing that irrelevant speech is more disruptive when it is made of a smaller than a larger number of voices. Furthermore, voices speaking from the same spatial location increased their disruptive effect compared to when they were presented from different locations. Thus, the level of difficulty was increased by decreasing the number of voices and by presenting them with dichotic listening, where some voices were presented to one ear of the participant while others were presented simultaneously to the other ear. Participants in the two training groups were expected to improve their memory since both include training in the method of loci. We also expected a reduction of the irrelevant speech effect due to memory training, and that this reduction would be larger in the *Memory+Attention* condition.

METHOD

Participants

Fifty-four participants with subjective cognitive decline were recruited in the community through advertisements in community centers and magazines for seniors. To be included in the study, participants had to complain about their memory but be cognitively intact. The complaint was operationalized by asking participants whether they felt that their memory was becoming worse (*Do you think that your memory is less good in recent years*?). To ensure that participants were cognitively intact, they completed an extensive neuropsychological trial testing memory (RL/RI-16, Van der Linden & Adam, 2004, Logical Memory I subtest of the Wechsler Memory Scale III, LM I; modified version, 1997), language (Boston Naming Test, Kaplan, Goodglass, & Weintraub, 1978) and executive (Stroop-Victoria, Troyer, Leach, & Strauss, 2006) measures. Performance on the RL/RI-16, the Stroop-Victoria (completion time), and the Boston Naming tests were deemed normal when scores were no more than 1.5 standard deviations below the mean of age- and education-matched normative samples. Performance on the Logical Memory test was considered normal based on education-adjusted cut-off scores used in the Alzheimer's Disease Neuroimaging Initiative (ADNI; Petersen et al., 2010). In addition, enrolled participants had to be older than 50 years of age, have French as their first language, normal or corrected vision and no history of hearing problems. Exclusion criteria were the following: dementia, alcoholism or substance abuse, presence or history of a neurological disorder, stroke or severe traumatic brain injury, presence or history of a severe psychiatric disorder, fibromyalgia, uncontrolled sleep apnea and general anaesthesia in the past 6 months.

Participants completed scales and questionnaires to assess their health and autonomy: the Geriatric Depression scale (GDS ; Yesavage et al., 1983), Hachinski Scale (Hachinski et al., 1975), Charlson Comorbidity Index (Charlson et al., 1987) and Activities of Daily Living-Prevention Instrument (ADL-PI; Galasko et al., 2006). These measures aimed to well-characterized the studied sample in order to compare it with those recruited in other intervention studies.

Design

Participants were randomly put into a *Memory+Attention* or *Memory+Memory* group. All participants received six one-hour training sessions (three sessions per week). In sessions 1 to 3, participants from the two groups learned and practiced the method of loci. In Sessions 4 to 6, participants in the to the *Memory+Attention* condition received the auditory training while continuing to practice the method of loci. Participants randomized to the *Memory+Memory* condition continued to practice the method of loci. Outcomes were measured one week prior to training (PRE1), one week after Session 3 (PRE2) which is just before introducing attentional training to the *Memory+Attention* group, and then one week after auditory training (POST**)** (See Figure 1). The study was double-blind: participants were not aware as to whether they were in the experimental or control group, and assessors were not aware of the participant's training condition. Identical versions of the outcome measurers were used for the different testing sessions.

The research was conducted at Research Center of the Institut universitaire de gériatrie de Montréal (CRIUGM), the protocol was approved by the Comité mixte d'éthique de la recherche du Regroupement Neuroimagerie/Québec (CMER-RNQ) and all participants completed a written informed consent prior to study participation.

Figure 1. Study Design

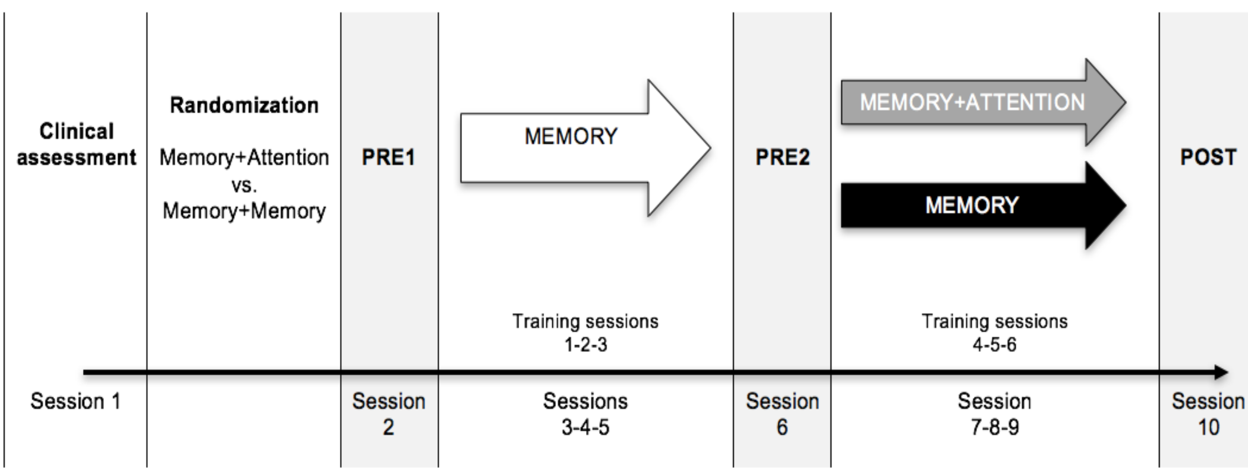

Figure 1. The figure shows the design from session 1 to 10. White arrow corresponds to the training which is common across both conditions. Grey (*Memory+Attention*) and black (*Memory+Memory*) arrows represent the differences between the two randomized conditions.

Intervention

In both conditions, training was provided face-to-face in small groups of 2-4 participants and led by an instructor. During sessions 1 to 3 participants learned the method of loci using an adapted version of the method, described in the MEMO program (Belleville et al., 2006). In session 1, participants completed various exercises to increase their ability to create vivid interactive images, selected a route in a familiar environment, and identified 12 landmarks on the route which would be used as loci. In session 2 and 3, participants practiced the method of loci using lists of concrete words. Ample guidance and feedback were provided by the therapist during those first three sessions to help participants master the technique. There was no limit on the time allowed to create each interactive image to start with, however it was reduced to 10 s per word on the first trial of session 3, and 5 s per word on the last trial of session 3.

During sessions 4 through 6, similar exercises were completed for participants randomized in the *Memory+Memory* condition. They were allowed five seconds per word to create each interactive image; feedback and guidance were not provided unless participants explicitly asked for a them. Participants in the *Memory+Attention* group completed the same exercises, combined with auditory attention training. The attention training involved presentation of concurrent irrelevant verbal noise while completing the memory tasks. The irrelevant noise was made of several voices reading different French texts simultaneously. Participants were asked to ignore the voices and to stay focused on the memory task. There were six levels of noise interference difficulty based on the number of voices and their locations (see figure 2) (Jones & Macken, 1995). The level of difficulty was gradually increased in an adaptive manner; participants moved from level to level according to their individual memory performance across trials. When the number of words correctly recalled was better or equal to that obtained from the previous trial, participants progressed to the next difficulty level. If performance dropped below that obtained from the previous trial, he/she remained on the same level for the following trial. If performance dropped below that obtained from the previous trial for a second consecutive trial, the participant was presented with the task corresponding to the previous difficulty level. Irrelevant noise was presented with the Plantronix Audio 550 headphones, using the E-prime 2 software.

Figure 2. The six interference levels used in the Memory+Attention training condition

Level of difficulty	Number of voices	Location
Level 1	6	6 in both ears
Level 2	6	3 in right ear, 3 in left ear
Level 3	4	4 in both ears
Level 4	4	2 in right ear, 2 in left ear
Level 5	2	2 in both ears
Level 6	2	1 in right ear, 1 in left ear

Outcomes measures

Participants were asked to memorize four lists of 12 visually presented words. Items were presented using the E-prime 2 software at a rate of 5 s per word on a computer screen and recall was by writing. There were two memory conditions: in silence vs. with verbal noise. The verbal noise was two short story excerpts spoken by a male and a female and presented dichotically with headsets during both encoding and recall. Two lists were memorized in silence and two lists were memorized with noise and conditions were presented according to an ABBA order, starting with the silence condition.

RESULTS

Baseline characteristics

Of the fifty-four participants initially recruited, seven did not meet the inclusion criteria due to being cognitively impaired. The remaining 47 participants were randomly assigned into the *Memory+Attention* (n = 23) or *Memory+Memory* (n = 24) conditions. Seven of them withdrew before the first training session (decline to participate), and thus 40 participants (*Memory+Attention*, n = 20; *Memory+Memory*, n = 20) completed the study. Clinical characteristics are presented in Table 1 for the participants who completed the training. Trained participants in the two groups were equivalent for age: $t(39) = -.25$, $p = .80$, education: $t(39) = -1.63$, $p = .11$, and sex: $\chi^2(1, n = 40) = .17$; $p = .68$. They were also equivalent for their performance on clinical tests and questionnaires (see Table 1, $p > .05$ in all cases).

Table 1

Characteristics of participants randomized to the Memory+Memory and Memory+Attention training conditions

	Memory+Attention	Memory+Memory
Sex (Males/Females)	3/17	4/16
Age (years)	67.60 (8.68)	67.00 (6.30)
Education (years)	15.70 (2.23)	14.20 (3.46)
GDS	2.55 (3.68)	1.25 (1.86)
Hachinski Scale	0.95 (1.19)	0.65 (0.81)
Charlson Comorbidity Index	0.55 (0.83)	0.55 (0.76)
ADL-PI	1.60 (1.93)	1.37 (2.79)

Note. Means scores are presented with standard deviations in parentheses. GDS = Geriatric Depression Scale; ADL-PI = The Activities of Daily Living-Prevention Instrument.

Effect of pure memory training (Session 1-3)

First, we assessed the effect of the method of loci on memory by comparing memory prior to training to memory after initial memory training (See Figure 3). This was done with a mixed ANOVA using Phase (PRE1; PRE2) and Noise (silence; noise) as within-subject factors, and Training condition (*Memory+Attention*; *Memory+Memory*) as a between-subject factor. All participants received a similar intervention but including the Training Condition allowed assessment of whether the two groups showed comparable learning on the method of loci. The dependent variable was the number of words correctly recalled. Noise had an effect on performance, $F(2,37) = 12.74$, $p < .01$; $\eta^2_p = .25$, due to better performance in silence than in a noisy environment. However, Noise did not interact with Phase, indicating that training did not reduce the effect of noise on performance. The training condition did not interact with Noise, but there was an unexpected interaction between Training condition and Testing Phase, $F(2,37) = 5.50$, $p < .05$; $\eta^2_p = .13$. The two groups were equivalent at PRE1 ($p = .76$), but participants in the *Memory+Attention* condition ($p < .01$) improved more than those in the

Memory+Memory condition ($p < .01$), even though both groups received similar training. As a result, their performance was no longer equivalent at PRE2. As mentioned below, this difference will be taken into account from now on by using performance on PRE2 as a covariate.

Figure 3. Number of words correctly recalled in silence and under noise for the *Memory+Attention* and the *Memory+Memory* training conditions from PRE1 to PRE2.

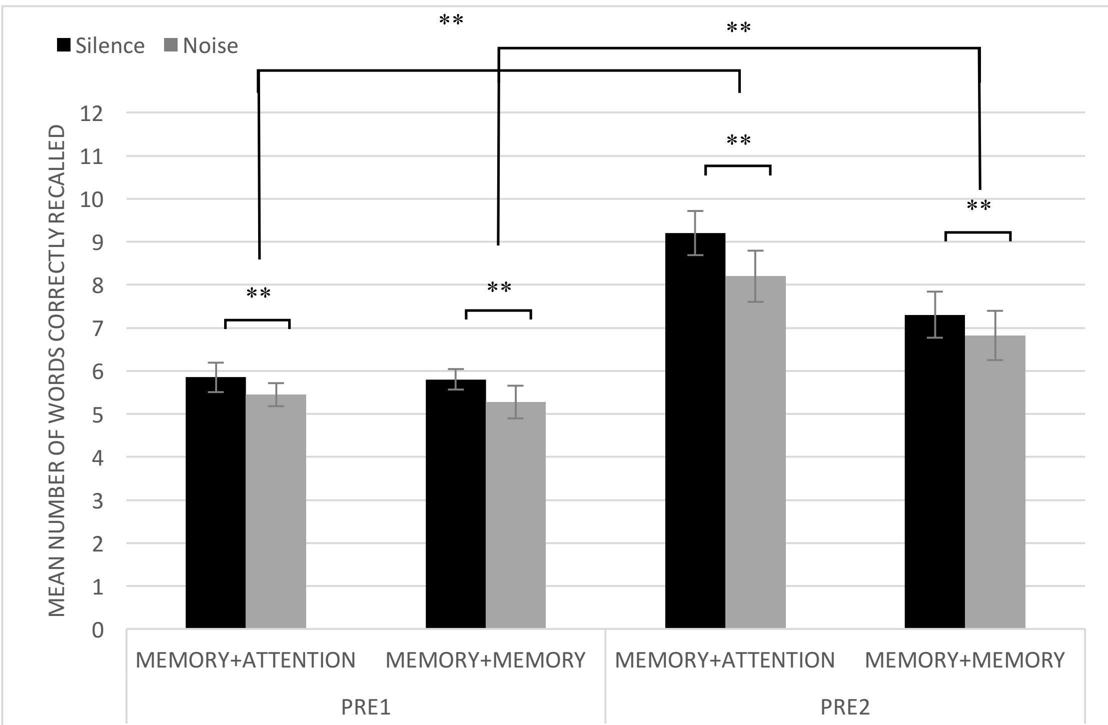

Figure 3. Number of words correctly recalled in silence (black) and under noise (gray) for the *Memory+Attention* and the *Memory+Memory* training conditions from PRE1 to PRE2. Error bars represent standard error. Word recall in silence and word recall under noise both increased similarly from PRE1 to PRE2, but more in *Memory+Attention* (**p <.01) than in *Memory+Memory* condition (**$p < .01$). Word recall performance was better in silence than under noise (**$p < .01$).

Auditory Attention Training effects

Results for PRE2 and POST are presented in Figure 4. To test the effect of attentional training, a mixed ANCOVA was conducted with Noise (silence; noise) as a within-subject factor, Training condition (*Memory+Attention*; *Memory+Memory*) as a between-subject factor, performance at PRE2 as a covariate, and using the number of words correctly recalled at POST as dependant variable. Using PRE2 as a covariate, rather than the entering Testing phase as a repeated factor, was done because we found a group difference at PRE2 as suggested by Egbewale, Lewis and Sim (2014). The baseline difference raised concern that randomization did not control for certain group differences that would potentially undermine the validity of group comparisons (Simons et al., 2016). None of the effects or interactions were significant including the Noise, $F(2,36) = 0.05$, $p = .83$, the Training condition, $F(2,36) = 0.08$, $p = .79$, or Noise x Training condition interaction, $F(2,36) = 0.013$, $p = .72$. Since it was not possible to include Testing Phase as a factor in this analysis, we assessed whether performance improved from PRE2 to POST with a Testing Phase (PRE2, POST) x Noise (silence, noise) mixed ANOVA, pooling data from all participants as there was no interaction involving the Training condition. A Testing Phase x Noise interaction was found, $F(1,39) = 4.89$, $p < .05$; $\eta^2_p = .11$. Post-hoc comparisons with Bonferroni adjustment showed that the interaction was due to a worst performance under noise than in silence at PRE2 ($p < .01$) but not at POST ($p = .96$).

Figure 4. Number of words correctly recalled in silence and under noise in the *Memory+Attention* and the *Memory+Memory* training conditions from PRE2 to POST.

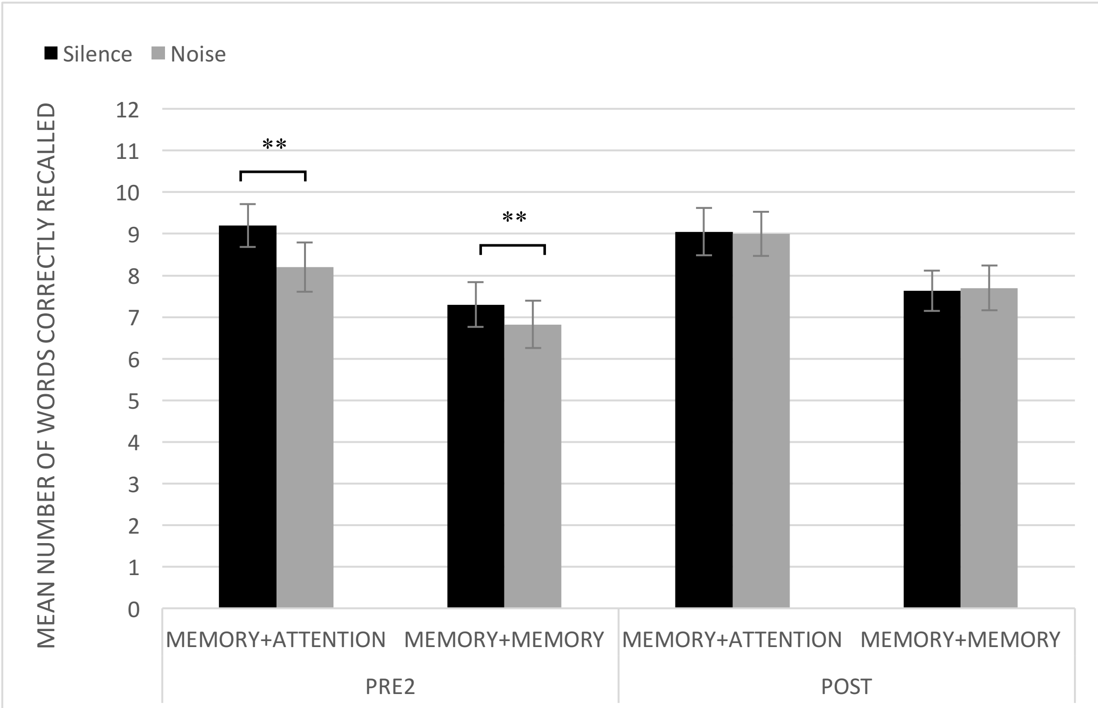

Figure 4. Number of words correctly recalled in silence (black) and under noise (gray) in the *Memory+Attention* and the *Memory+Memory* training conditions from PRE2 to POST. Error bars represent standard error. There was no effect of the training conditions in POST when controlling for performance in PRE2. Word recall performance was better in silence than under noise (**$p < .01$) at PRE2 but not at POST.

DISCUSSION

This study examined the effect of memory training or combined memory and attentional training on elderly peoples' ability to memorize in noisy conditions. A question we addressed was whether improving memory with the method of loci reduce the detrimental effect of noise on word recall, and whether receiving *Memory+Attention* training further reduce effect of irrelevant noise.

The results showed that irrelevant speech negatively hinders word recall. The detrimental effect of irrelevant speech was found on word recall in both PRE1 and PRE2, which confirms the results found in many previous studies (Tun, O'Kabe, & Wingfield, 2002;

Bell, Buchner, & Mund 2008; Meijer, De Groot, Van Boxtel, Van Gerven, & Jolles, 2006). It also supports the relevance of investigating whether memory under noisy conditions can be improved through memory or attentional training.

Memory training increased word recall over the first three training sessions, as expected (that is, from PRE1 to PRE2). This is consistent with the results found in numerous studies indicating that the method of loci is an efficient strategy and can be used to improve memory in older adults. Our main objective was to reduce the detrimental effect of irrelevant noise on memory. Interestingly, we found that this was the case as the irrelevant speech effect was no longer present at POST: recall under noisy condition was equivalent to word recall under silent condition. However, and contrary to our expectations, the *Memory+Attention* training condition did not result in a larger reduction of the irrelevant speech effect. Thus, there was no added benefit from practicing the method of loci under irrelevant speech compared to the traditional learning of the method in silence. However, inspection of Figure 4 indicates that by Session 6, memory training alone completely removed the irrelevant speech effect. Thus, there was not possibility to observe a further benefit from attentional training

Importantly, memory training increased both word recall and word recall with noise when comparing PRE1 to PRE2, and it removed the detrimental effect of noise on performance when comparing PRE2 to POST. This indicates that method of loci training can be used under background noise and that it improving memory with the method can reduce the detrimental effect of irrelevant speech on memory. This is important since there is currently little evidence for transfer to tasks that differ from those trained in strategy training (see Brehmer, Kalpouzos, Wenger, & Lövdén, 2014; Zelinsky, 2009; Rebok et al., 2007; Kelly et al., 2014; Simons et al., 2016 for reviews; Ball et al., 2002). This transfer could be due to the fact that through the creation of interactive images, method of loci leads to visual encoding of presented words instead of the verbal encoding. A visual encoding might reduce vulnerability to verbal interference, since distraction in aging is more likely in unimodal (e.g., verbal-verbal) than in cross-modal paradigms (e.g., visual-verbal) (Guerreiro, Murphy, & Van Gerven, 2010).

There are a few limitations which need to be mentioned. First, a significant and unexpected group difference was found from at PRE2 due to the fact that the participants in the *Memory+Attention* condition showed a larger improvement even though both groups had received the same training. As a result, we were constrained to control for PRE2 performance which prevented us to rely on a three-way ANOVA like that which compared PRE1 and PRE2. It is thus possible that the two training groups were not equivalent before training, and that some unknown variables have impacted the results. The content of the adaptive speech inhibition training which was based on the number of voices and their locations might not have been appropriate, and the dose may have been insufficient. Finally, better results could have been obtained if training memory and inhibition had been done in isolation, as was the case in Mozolic and colleagues (2011).

In summary, our results support earlier findings indicating that background irrelevant speech has a detrimental effect on word recall in older adults. We show that strategy training leads to memory increase in silent conditions after three sessions, but also under background irrelevant speech, where the noise effect on recall was completely gone after six sessions. This suggests that extended practice is necessary to optimize effects on recall ability. Results did not show evidence that the addition of an attentional training improved these effects.

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REFERENCES

Anderson, N. D., Craik, F. I., & Naveh-Benjamin, M. (1998). The attentional demands of encoding and retrieval in younger and older adults: Evidence from divided attention costs. *Psychology and Aging*, *13*(3), 405–423. doi:10.1037/0882-7974.13.3.405

Ball, K., Berch, D. B., Helmers, K. F., Jobe, J. B., Leveck, M. D., Marsiske, M., . . . Unverzagt, F. W. (2002). Effects of cognitive training interventions with older adults: A randomized controlled trial. *The Journal of the American Medical Association. 288*(18), 2271–2281. doi:10.1001/jama.288.18.2271

Bell, R., Buchner, A., & Mund, I. (2008). Age-related differences in irrelevant-speech effects. *Psychology and Aging*, 23(2), 377–391. doi:10.1037/0882-7974.23.2.377

Belleville, S., Clément, F., Mellah, S., Gilbert, B., Fontaine, F., & Gauthier, S. (2011). Training-related brain plasticity in subjects at risk of developing Alzheimer's disease. *Brain, 134*(6), 1623–1634. doi:10.1093/brain/awr037

Belleville, S., Gilbert, B., Fontaine, F., Gagnon, L., Ménard, É., & Gauthier, S. (2006). Improvement of episodic memory in persons with mild cognitive impairment and healthy older adults: Evidence from a cognitive intervention program. *Dementia and Geriatric Cognitive Disorders, 22*(5–6), 486–499. doi:10.1159/000096316

Belleville, S., Hudon, C., Bier, N., Brodeur, C., Gilbert, B., Grenier, S., . . . Gauthier, S. (2018). MEMO+: Efficacy, durability and effect of cognitive training and psychosocial intervention in individuals with mild cognitive impairment. *Journal of the American Geriatrics Society*, 1–9. doi:10.1111/jgs.15192

Bherer, L., Kramer, A. F., Peterson, M. S., Colcombe, S., Erickson, K., & Becic, E. (2008). Transfer effects in task-set cost and dual-task cost after dual-task training in older and younger adults: Further evidence for cognitive plasticity in attentional control in late adulthood. *Experimental Aging Research, 34*(3), 188–219.

doi:10.1080/03610730802070068

Bier, B., de Boysson, C., & Belleville, S. (2014). Identifying training modalities to improve multitasking in older adults. *Age*, *36*(4), 1–16. doi:10.1007/s11357-014-9688-2

Boman, E. (2004). The effects of noise and gender on children's episodic and semantic memory. *Scandinavian journal of psychology*, *45*(5), 407–416. doi:10.1111/j.1467-9450.2004.00422.x

Bower, G. H. (1970). Analysis of a mnemonic device: Modern psychology uncovers the powerful components of an ancient system for improving memory. *American Scientist*, *58*(5), 496–510.

Brehmer, Y., Kalpouzos, G., Wenger, E., & Lövdén, M. (2014). Plasticity of brain and cognition in older adults. *Psychological Research*, *78*(6), 790–802. doi:10.1007/s00426–014–0587–z

Charlson, M. E., Pompei, P., Ales, K. L., & MacKenzie, C. R. (1987). A new method of classifying prognostic comorbidity in longitudinal studies: Development and validation. *Journal of Chronic Diseases*, *40*(5), 373–383. doi:10.1016/0021-9681(87)90171-8

Colle, H. A., & Welsh, A. (1976). Acoustic masking in primary memory. *Journal of Verbal Learning and Verbal Behavior*, *15*(1), 17–31. doi:10.1016/S0022-5371(76)90003-7

Egbewale, B. E., Lewis, M., & Sim, J. (2014). Bias, precision and statistical power of analysis of covariance in the analysis of randomized trials with baseline imbalance: A simulation study. *BMC Medical Research Methodology*, *14*(1), 49–60. doi:10.1186/1471-2288-14-49

Engvig, A., Fjell, A. M., Westlye, L. T., Skaane, N. V., Sundseth, Ø., & Walhovd, K. B. (2012). Hippocampal subfield volumes correlate with memory training benefit in subjective memory impairment. *Neuroimage*, *61*(1), 188–194. doi:10.1016/j.neuroimage.2012.02.072

Enmarker, I. (2004). The effects of meaningful irrelevant speech and road traffic noise on teachers' attention, episodic and semantic memory. *Scandinavian Journal of Psychology*, *45*(5), 393–405. doi:10.1111/j.1467-9450.2004.00421.x

Gagnon, L. G., & Belleville, S. (2012). Training of attentional control in mild cognitive impairment with executive deficits: Results from a double-blind randomised controlled study. *Neuropsychological Rehabilitation*, 1–27. doi:10.1080/09602011.2012.691044

Galasko, D., Bennett, D. A., Sano, M., Marson, D., Kaye, J., & Edland, S. D. (2006). ADCS Prevention Instrument Project: Assessment of instrumental activities of daily living for community–dwelling elderly individuals in dementia prevention clinical trials. *Alzheimer Disease & Associated Disorders*, *20*, S152–S169. doi:10.1097/01.wad.0000213873.25053.2b

Gross, A. L., Parisi, J. M., Spira, A. P., Kueider, A. M., Ko, J. Y., Saczynski, J. S., . . . Rebok, G. W. (2012). Memory training interventions for older adults: A meta-analysis. *Aging & Mental health, 16*(6), 722–734. doi:10.1080/13607863.2012.667783

Guerreiro, M. J., Murphy, D. R., & Van Gerven, P. W. (2010). The role of sensory modality in age-related distraction: A critical review and a renewed view. *Psychological Bulletin, 136*(6), 975–1022. doi:10.1037/a0020731

Hachinski, V. C., Iliff, L. D., Zilhka, E., Du Boulay, G. H., McAllister, V. L., Marshall, J., . . . Symon, L. (1975). Cerebral blood flow in dementia. *Archives of Neurology*, *32*(9), 632–637. doi:10.1001/archneur.1975.00490510088009

Hasher, L., & Zacks, R. T. (1988). Working memory, comprehension, and aging: A review and a new view. In G. H. Bower (Ed.), *The Psychology of Learning and Motivation* (Vol. 22, pp. 193–225). New York, NY: Academic Press.

Hygge, S., Boman, E., & Enmarker, I. (2003). The effects of road traffic noise and meaningful irrelevant speech on different memory systems. *Scandinavian Journal of Psychology*, *44*(1), 13–21. doi:10.1111/1467-9450.00316

Jones, D. M., & Macken, W. J. (1995). Auditory babble and cognitive efficiency: Role of number of voices and their location. *Journal of Experimental Psychology: Applied*, *1*(3), 216–226. doi:10.1037/1076-898X.1.3.216

Kaplan, E. F., Goodglass, H., & Weintraub, S. (1983). Boston Naming Test (2nd edition). *Philadelphia: Lea & Febiger*.

Kelly, M. E., Loughrey, D., Lawlor, B. A., Robertson, I. H., Walsh, C., & Brennan, S. (2014). The impact of cognitive training and mental stimulation on cognitive and everyday functioning of healthy older adu lts: A systematic review and meta–analysis. *Ageing Research Reviews*, *15*, 28–43. doi:10.1016/j.arr.2014.02.004

Kerns, K. A., MacSween, J., Vander Wekken, S., & Gruppuso, V. (2010). Investigating the efficacy of an attention training programme in children with foetal alcohol spectrum disorder. *Developmental Neurorehabilitation*, *13*(6), 413–422. doi:10.3109/17518423.2010.511421

Knez, I., & Hygge, S. (2002). Irrelevant speech and indoor lighting: Effects on cognitive performance and self-reported affect. *Applied Cognitive Psychology*, *16*(6), 709–718. doi:10.1002/acp.829

Kramer, A. F., Larish, J. F., & Strayer, D. L. (1995). Training for attentional control in dual task settings: A comparison of young and old adults. *Journal of Experimental Psychology: Applied*, *1*(1), 50–76. doi:10.1037/1076-898X.1.1.50

Langlois, A.-S., & Belleville, S. (2014). Subjective cognitive complaint in healthy older adults: Identification of major domains and relation to objective performance. *Aging, Neuropsychology, and Cognition, 21*(3), 257–282. doi:10.1080/13825585.2013.795928

LeCompte, D. C. (1994). Extending the irrelevant speech effect beyond serial recall. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *20*(6), 1396–1408. doi:10.1037/0278-7393.20.6.1396

Meijer, W. A., De Groot, R. H., Van Boxtel, M. P., Van Gerven, P. W., & Jolles, J. (2006). Verbal learning and aging: Combined effects of irrelevant speech, interstimulus interval, and education. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences, 61*(5), 285–294. doi:10.1093/geronb/61.5.P285

Miles, C., Jones, D. M., & Madden, C. A. (1991). Locus of the irrelevant speech effect in short-term memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *17*(3), 578–584. doi:10.1037/0278-7393.17.3.578

Mozolic, J. L., Long, A. B., Morgan, A. R., Rawley-Payne, M., & Laurienti, P. J. (2011). A cognitive training intervention improves modality-specific attention in a randomized controlled trial of healthy older adults. *Neurobiology of Aging*, *32*(4), 655–668. doi:10.1016/j.neurobiolaging.2009.04.013

Nyberg, L., Sandblom, J., Jones, S., Neely, A. S., Petersson, K. M., Ingvar, M., & Bäckman, L. (2003). Neural correlates of training-related memory improvement in adulthood and aging. *Proceedings of the National Academy of Sciences*, *100*(23), 13728–13733. doi:10.1073/pnas.1735487100

Petersen, R. C., Aisen, P. S., Beckett, L. A., Donohue, M. C., Gamst, A. C., Harvey, D. J., . . . Trojanowski, J. Q. (2010). Alzheimer's disease Neuroimaging Initiative (ADNI) clinical characterization. *Neurology*, *74*(3), 201–209. doi:10.1212/WNL.0b013e3181cb3e25

Pronk, M., Deeg, D. J., Festen, J. M., Twisk, J. W., Smits, C., Comijs, H. C., & Kramer, S. E. (2013). Decline in older persons' ability to recognize speech in noise: The influence of demographic, health-related, environmental, and cognitive factors. *Ear and Hearing*, *34*(6), 722–732. doi:10.1097/AUD.0b013e3182994eee

Rebok, G. W., Carlson, M. C., & Langbaum, J. B. (2007). Training and maintaining memory abilities in healthy older adults: Traditional and novel approaches. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences, 62*(Special Issue 1), 53–61. doi:10.1093/geronb/62.special_issue_1.53

Robertson-Tchabo, E. A., Hausman, C. P., & Arenberg, D. (1976). A classical mnemonic for older learners: A trip that works! *Educational Gerontology: An International Quarterly*, *1*(3), 215–226. doi:10.1080/0360127760010301

Rose, T. L., & Yesavage, J. A. (1983). Differential effects of a list-learning mnemonic in three age groups. *Gerontology*, *29*(5), 293–298.

Rouleau, N., & Belleville, S. (1996). Irrelevant speech effect in aging: An assessment of inhibitory processes in working memory. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences,* *51*(6), 356–363. doi:10.1093/geronb/51B.6.P356

Salamé, P., & Baddeley, A. (1987). Noise, unattended speech and short-term memory. *Ergonomics 30*(8), 1185–1194. doi:10.1080/00140138708966007

Simons, D. J., Boot, W. R., Charness, N., Gathercole, S. E., Chabris, C. F., Hambrick, D. Z., & Stine–Morrow, E. A. (2016). Do “brain–training” programs work? *Psychological Science in the Public Interest, 17*(3), 103–186. doi:10.1177/1529100616661983

Stigsdotter, A., & Bäckman, L. (1989). Multifactorial memory training with older adults: How to foster maintenance of improved performance. *Gerontology*, *35*(5-6), 260–267. doi:10.1159/000213035

Troyer, A. K., Leach, L., & Strauss, E. (2006). Aging and response inhibition: normative data for the Victoria Stroop Test. *Aging, Neuropsychology, and Cognition*, *13*(1), 20–35. doi:10.1080/138255890968187

Tun, P. A. (1998). Fast noisy speech: Age differences in processing rapid speech with background noise. *Psychology and Aging*, *13*(3), 424–434. doi:10.1037/0882-7974.13.3.424.

Tun, P. A., O’kane, G., & Wingfield, A. (2002). Distraction by competing speech in young and older adult listeners. *Psychology and Aging*, *17*(3), 453–467. doi:10.1037/0882-7974.17.3.453

Van der Linden, M., Coyette, F., Poitrenaud, J., Kalafat, M., Calacis, F., Wyns, C., . . . et les membres du GREMEM (2004). L'épreuve de rappel libre/rappel indicé à 16 items (RL/RI-16). In M. Van der Liden, S. Adam, A. Agniel, C. Baisset Mouly, et al. (Eds.), *L'évaluation des troubles de la mémoire : Présentation de quatre tests de mémoire épisodique (avec leur étalonnage).* Marseille, France : Solal.

Van Gerven, P. W., Meijer, W. A., Vermeeren, A., Vuurman, E. F., & Jolles, J. (2007). The irrelevant speech effect and the level of interference in aging. *Experimental Aging Research, 33*(3), 323–339. doi:10.1080/03610730701319145

van't Hooft, I., Andersson, K., Bergman, B., Sejersen, T., Von Wendt, L., & Bartfai, A. (2005). Beneficial effect from a cognitive training programme on children with acquired brain injuries demonstrated in a controlled study. *Brain Injury*, *19*(7), 511–518. doi:10.1080/02699050400025224

van't Hooft, I., Andersson, K., Bergman, B., Sejersen, T., von Wendt, L., & Bartfai, A. (2007). Sustained favorable effects of cognitive training in children with acquired brain injuries. *NeuroRehabilitation*, *22*(2), 109–116.

Verhaeghen, P. (2016). Memory Training and Mnemonics. In S. Krauss Whitbourne (Ed.). *The Encyclopedia of Adulthood and Aging* (pp. 892–894). John Wiley & Sons, Inc. doi:10.1002/9781118521373.wbeaa076

Verhaeghen, P., Marcoen, A., & Goossens, L. (1992). Improving memory performance in the aged through mnemonic training: A meta-analytic study. *Psychology and Aging, 7*(2), 242–251. doi:10.1037/0882-7974.7.2.242

Wais, P. E., & Gazzaley, A. (2014). Distractibility during retrieval of long-term memory: Domain-general interference, neural networks and increased susceptibility in normal aging. *Frontiers in Psychology, 5*(180), 1–12. doi:10.3389/fpsyg.2014.00280

Wechsler, D. (1997). *Wechsler Memory Scale–Third Edition.* San Antonio, TX: The Psychological Corporation.

Wiley, T. L., Cruickshanks, K. J., Nondahl, D. M., Tweed, T. S., Klein, R., & Klein, B. E. (1998). Aging and word recognition in competing message. *Journal-American Academy of Audiology*, *9*, 191–198.

Wilkinson, A. J., & Yang, L. (2012). Plasticity of inhibition in older adults: Retest practice and transfer effects. *Psychology and Aging*, *27*(3), 606–615. doi:10.1037/a0025926

Wilkinson, A. J., & Yang, L. (2015). Long-term maintenance of inhibition training effects in older adults: 1-and 3-year follow-up. *Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, *71*(4), 622–629.doi:10.1093/geronb/gbu179

Willis, S. L. & Belleville, S. (2016). Cognitive training in later adulthood. In K. W. Shaie and S. L. Willis (Eds). *Handbook of the psychology of aging* (8th edition, p. 219–243). London, UK: Elsevier.

Willis, S. L., Cornelius, S. W., Blow, F. C., & Baltes, P. B. (1983). Training research in aging: Attentional processes. *Journal of Educational Psychology*, *75*(2), 257–270. doi:10.1037/0022-0663.75.2.257

Yesavage, J. A., & Rose, T. L. (1983). Concentration and mnemonic training in elderly subjects with memory complaints: A study of combined therapy and order effects. *Psychiatry Research*, *9*(2), 157–167. doi:10.1016/0165–1781(83)90037–9

Zelinski, E. M. (2009). Far transfer in cognitive training of older adults. *Restorative Neurology and Neuroscience*, *27*(5), 455–471. doi:10.3233/RNN–2009–0495

Chapitre V

Discussion générale

5.1. Rappel des objectifs et synthèse des résultats

Cette thèse avait pour objectif principal d'étudier si le fait d'enrichir un entraînement mnésique avec diverses conditions représentantes de la vraie vie était efficace chez des personnes âgées avec plainte mnésique (ou DCS), et de mesurer si ces conditions favorisent le transfert de contexte à l'aide d'outils à la fois objectifs et près du quotidien. La pertinence de ces travaux tient d'abord du fait que peu d'études ont pu mettre en évidence qu'un entraînement cognitif puisse avoir des effets dans la vie de tous les jours, i.e., un transfert de contexte (Kelly et al., 2014 ; Simons et al., 2016). Ensuite, la population visée par ce travail de recherche est l'une des plus susceptibles de bénéficier d'un entraînement cognitif, puisque les individus avec DCS présentent des risques plus importants – comparativement à la population générale – de se trouver dans un stade prodromique de la MA (Jessen et al., 2014),

Nous souhaitions tout particulièrement utiliser la RV pour promouvoir et mesurer les effets de transfert de contexte. Une première étape visait donc à construire une tâche de mémoire en RV immersive. Ensuite, nous voulions nous assurer de sa faisabilité et de sa validité, afin que celle-ci puisse être utilisée dans les études subséquentes.

Nous voulions ensuite examiner si des effets de transfert allaient être mis en évidence sur des mesures objectives en RV reflétant des situations complexes quotidiennes, jusqu'ici peu utilisées pour évaluer le transfert. Ces effets seraient comparés à ceux obtenus sur une mesure auto-rapportée, un outil plus fréquemment utilisé, mais comportant des faiblesses liées à la subjectivité des réponses obtenues. Nous désirions de même tester si un entraînement mnésique classique enrichi d'exercices en RV pouvait mener à des effets supérieurs de transfert de contexte. Parallèlement, un objectif secondaire était d'explorer si la dose d'entraînement reçue pouvait influencer les effets de l'entraînement, et surtout les effets de transfert.

Afin de poursuivre dans la perspective de rapprocher les interventions des conditions de la vie réelle, nous avons enrichi un entraînement mnésique classique avec des exercices attentionnels visant l'inhibition de bruit verbal ambiant, puisque la mémorisation au quotidien se fait fréquemment en contexte bruyant. Nous voulions tester si le fait de créer des conditions d'entraînement mnésique reflétant cette situation complexe du quotidien pouvait aider à améliorer la performance de mémoire, particulièrement en condition de bruit. De façon spécifique, nous voulions évaluer si un entraînement mnésique additionné d'un entraînement attentionnel auditif réduirait l'impact du bruit sur la mémorisation.

Les différents objectifs de la thèse sont couverts par l'entremise de trois articles empiriques. Dans les sections suivantes, les résultats principaux de chacun d'eux seront résumés. Par la suite, nous aborderons les implications principales des résultats obtenus. Enfin, nous discuterons des limites de la thèse et des perspectives futures émanant de ces travaux.

5.1.1. Synthèse des résultats de l'article 1

L'article 1 a permis de concevoir La boutique virtuelle, une toute nouvelle tâche de RV immersive conçue pour évaluer la mémoire épisodique dans un contexte près du quotidien. Ensuite, nous souhaitions en évaluer la faisabilité et la validité chez une population d'adultes jeunes et âgés. Dans cette tâche, le participant est immergé dans une boutique virtuelle. Il doit y mémoriser une liste de 12 produits, pour ensuite les rechercher et les sélectionner suite à un court délai. L'aspect innovateur de cette tâche réside dans le fait qu'elle utilise la RV immersive et la marche réelle comme mode de navigation, affichant ainsi un plus grand degré de réalisme que les tâches équivalentes existantes. Deux études ont été menées pour répondre aux objectifs de l'article 1.

La première étude visait d'une part à évaluer la faisabilité de la tâche, et d'autre part à en mesurer la validité de construit via la méthode de différence de groupes. Pour ce faire, 20 jeunes adultes et 19 personnes âgées ont complété La boutique virtuelle, alors que plusieurs variables étaient mesurées (nombre de bonnes réponses, nombre d'erreurs, nombre d'objets sélectionnés, nombre d'objets validés, temps d'initiation, temps de compétition).

L'une des hypothèses était que La boutique virtuelle affiche une bonne faisabilité auprès des deux populations (jeune et âgée), c'est-à-dire : que les participants soient capables de se déplacer dans l'environnement en utilisant la marche ; qu'ils utilisent le pointeur pour sélectionner des objets et en valider/annuler la sélection ; que le score de bonnes réponses affiche une certaine variabilité entre les participants ; et que la tâche soit complétée dans une courte période de temps. L'autre hypothèse était que les jeunes adultes obtiennent une performance supérieure à celle des personnes âgées, tel qu'anticipé dans une tâche de mémoire épisodique, appuyant ainsi la validité de construit de la tâche.

Les résultats obtenus appuient les deux hypothèses posées. D'abord, ils indiquent que la tâche est faisable. En effet, les personnes jeunes et âgées ont toutes été en mesure de se déplacer dans l'environnement et d'utiliser le pointeur virtuel pour sélectionner, valider ou annuler des objets. Le rendement affichait une bonne variabilité, sans effet plafond ou plancher, et tous ont pu terminer la tâche sous la barre des 15 minutes, un délai raisonnable pour une tâche mnésique. Les personnes jeunes ont obtenu des scores de performance plus élevés que ceux des personnes âgées – soit un plus grand nombre de bonnes réponses et des temps d'initiation et de complétion plus courts – tel que vu dans les tâches de mémoire classiques, ce qui appuie la validité de construit de La boutique virtuelle.

La deuxième étude avait pour but d'évaluer la validité de construit de La boutique virtuelle via la méthode de validité convergente, ainsi que sa validité écologique, en étudiant ses liens avec un questionnaire auto-rapporté. Pour y arriver, trente-cinq individus répondant aux critères d'un DCS ont complété La boutique virtuelle, une tâche de mémoire épisodique (RL/RI-16), une tâche exécutive (Stroop-Victoria) et un questionnaire évaluant la performance de mémoire au quotidien (MMQ-Capacité). Un score de capacité de mémoire spécifique aux tâches d'achats quotidiens a été calculé à partir du MMQ (MMQ-Shopping).

La première hypothèse posée était que la performance à La boutique virtuelle soit corrélée positivement avec le score de rappel libre différé du RL/RI-16, appuyant la validité de construit de la tâche. La seconde hypothèse supposait la présence d'une corrélation négative entre la performance à La boutique virtuelle et le score de plainte cognitive du MMQ-Shopping, appuyant la validité écologique de la tâche. La dernière hypothèse présentée prédisait que la performance obtenue à La boutique virtuelle corrèle avec le score d'inhibition cognitive du Stroop-Victoria, supposant que la tâche de RV possédait probablement une composante exécutive.

En concordance avec les hypothèses, le nombre de bonnes réponses obtenues dans La boutique virtuelle s'est montré corrélé modérément à la performance du RL/RI-16, attestant que la tâche évalue la mémoire épisodique. Comme la corrélation n'est que modérée, il se peut que d'autres fonctions cognitives soient impliquées dans La boutique virtuelle. Par ailleurs, aucune relation n'a été mise en évidence entre le score d'inhibition cognitive du Stroop-Victoria, suggérant que La boutique virtuelle n'évalue pas directement cette fonction cognitive. Également, deux mesures de performance obtenues suite à la compétition de la tâche de RV étaient corrélées modérément avec le score du MMQ-Shopping, soit le nombre de bonnes réponses et le temps nécessaire avant d'offrir une première réponse. Ainsi, il est suggéré que la tâche reflète le fonctionnement mnésique quotidien, tel qu'attendu.

En résumé, il apparaît que La boutique virtuelle offre une bonne faisabilité auprès des personnes jeunes et âgées. Les résultats appuient également tant la validité de construit que la validité écologique de la tâche.

5.1.2. Synthèse des résultats de l'article 2

Les buts précis poursuivis par l'article 2 étaient les suivants : 1) évaluer les effets de transfert de contexte d'un entraînement mnésique avec des tâches de RV et les comparer à ceux mesurés à l'aide d'un questionnaire auto-rapporté ; 2) tester si le fait d'ajouter des exercices en RV à un entraînement mnésique pouvait accroître les effets de transfert de contexte, en créant des conditions d'entraînement plus près du quotidien ; 3) examiner si les effets de l'entraînement, tant sur le plan de l'efficacité que du transfert de contexte, différeraient selon le nombre de sessions reçues (i.e., la dose d'entraînement). Afin de répondre à ces objectifs, 40 personnes âgées en santé avec plainte mnésique ont réalisé un entraînement à la méthode des lieux, celui étant enrichi (RV+) ou non (RV-) d'exercices mnésiques exécutés dans La boutique virtuelle. L'intervention était réalisée en petits groupes, et s'échelonnait sur six sessions d'une heure chacune réparties sur deux semaines. L'efficacité de l'entraînement était mesurée à l'aide d'une tâche de rappel de mots. Pour sa part, le transfert de contexte était évalué par l'entremise de trois tâches : un rappel de mots effectué dans La boutique virtuelle, un rappel de mots en contexte de double-tâche complété dans La promenade en voiture virtuelle et un questionnaire auto-rapporté portant sur la capacité mnésique au quotidien. Ces tâches étaient administrées avant l'entraînement (PRÉ), après trois séances d'entraînement (POST 3) et suite à la sixième et dernière séance d'entraînement (POST 6).

La principale hypothèse était que, suite à l'entraînement, des effets de transfert allaient être mis en évidence sur les deux mesures de transfert de contexte en RV. Par contre, nous supposions que ces effets ne seraient pas présents sur la mesure de transfert de contexte auto-rapportée, en concordance avec la littérature actuelle. Il était également supposé que les participants du groupe RV+ montrent des effets de transfert de contexte supérieurs à ceux du groupe RV-. Enfin, il était attendu que le rendement des participants augmente de façon graduelle au fil des séances d'entraînement (PRÉ < POST 3 < POST 6), et ce sur toutes les mesures.

Conformément à la première hypothèse, les participants des deux groupes ont vu leur performance progresser sur les deux tâches de RV suite à l'entraînement. La mesure de capacité mnésique auto-rapportée n'a montré aucun changement. Notons que l'amélioration mesurée à la tâche de La promenade en voiture virtuelle s'est vu corrélée à l'amélioration obtenue à la tâche d'efficacité, suggérant un effet au-delà du simple effet de pratique. Par ailleurs, les résultats de l'étude n'ont pas permis de confirmer la seconde hypothèse, puisque les deux groupes n'ont affiché aucune différence sur les mesures de transfert suite à l'intervention, peu importe le moment de mesure ou la tâche utilisée. Rien n'indique donc ici que l'enrichissement d'un entraînement mnésique à l'aide d'exercices de RV puisse faire la promotion du transfert de contexte. Enfin, contrairement à ce qui était prévu, les effets n'étaient pas différents après trois ou six séances d'entraînement. Trois séances ont suffi pour mettre en évidence des améliorations sur la mesure d'efficacité et les deux mesures de RV, et celles-ci n'ont pas changé suite à la réalisation des trois séances supplémentaires.

5.1.3. Synthèse des résultats de l'article 3

Le troisième article avait comme but de tester si un entraînement mnésique comportant des exercices attentionnels, ciblant plus précisément l'inhibition du bruit ambiant, pouvait se montrer plus efficace qu'un entraînement mnésique seul. À cet effet, 40 personnes âgées en santé avec plainte mnésique ont été randomisées en deux conditions d'entraînement mnésique, soit MÉMOIRE+MÉMOIRE et MÉMOIRE+ATTENTION. Les participants des deux conditions ont d'abord été soumis à trois séances d'entraînement de 60 minutes où ils apprenaient la méthode des lieux. Les exercices se faisaient alors dans un environnement silencieux. Puis, dans la condition MÉMOIRE+ATTENTION, trois séances d'entraînement supplémentaires de 60 minutes étaient dédiées à des exercices de pratique de la méthode des lieux en contexte de bruit verbal ambiant. Dans chacun des exercices, le niveau de distractibilité du bruit augmentait graduellement selon la performance mnésique individuelle. Dans la condition MÉMOIRE+MÉMOIRE, trois séances d'exercices similaires étaient également complétées, mais dans un environnement sans bruit. Les effets de l'intervention étaient mesurés grâce à deux tâches de rappel de 12 mots, l'une effectuée dans un environnement silencieux, l'autre effectuée en contexte de bruit verbal. Ces mesures étaient prises à trois reprises, soit avant l'intervention (PRÉ 1), suite à la troisième séance (PRÉ 2) et après l'intervention (POST). La mesure PRÉ 2 permettait de s'assurer d'obtenir une nouvelle mesure de base avant que les deux conditions d'entraînement ne se distinguent ; rappelons que les séances 1 à 3 étaient identiques pour tous les participants.

Il était d'abord attendu que les participants des deux conditions voient leur performance mnésique s'améliorer suite à l'apprentissage de la méthode des lieux (PRÉ 2). Toutefois, l'hypothèse centrale était que, après avoir reçu l'entraînement attentionnel (du PRÉ 2 au POST), le groupe MÉMOIRE+ATTENTION montrerait une réduction plus importante de l'effet délétère du bruit sur la mémoire, comparativement au groupe MÉMOIRE+MÉMOIRE.

Les résultats obtenus ont d'abord mis en évidence un effet négatif du bruit sur la performance mnésique, tel que précédemment montré dans la littérature. Ensuite, comme le prédisait l'hypothèse 1, les participants présentaient une amélioration du rappel de mots suite à l'apprentissage initial de la méthode des lieux. Après trois séances, cette amélioration était présente autant lorsque la tâche était faite en silence que dans le bruit, et après six séances, l'effet délétère du bruit sur la performance de mémoire avait disparu. Par ailleurs, les effets de l'entraînement MÉMOIRE+ATTENTION n'ont pas différé de ceux obtenus suite à l'entraînement mnésique seul (MÉMOIRE+MÉMOIRE).

En résumé, l'apprentissage de la méthode des lieux améliore la performance de mémoire en contexte bruyant et une pratique prolongée élimine l'effet négatif du bruit. Par ailleurs, il ne semble pas que le fait de coupler un entraînement mnésique à des exercices attentionnels visant l'inhibition auditive puisse amplifier ces effets, que ce soit en condition silencieuse ou bruyante.

5.2. L'utilisation de la réalité virtuelle immersive avec les personnes âgées

5.2.1. Faisabilité

L'étude de la faisabilité de l'utilisation de La boutique virtuelle dans une population jeune et âgée était un objectif important de la thèse. D'abord, l'utilisation du matériel de RV immersive a été très peu étudié chez les personnes âgées. Il a aussi été montré que les gens âgés ont moins tendance que les jeunes à intégrer la technologie (e.g., ordinateur, internet, etc.) dans leur vie (Czaja et al., 2006). Quatre facteurs pourraient particulièrement nuire à l'utilisation de la RV chez les personnes âgées : la technophobie, le statut perceptivo-moteur, les cybermalaises, et la complexité d'utilisation (Déjos, Sauzéon, & N'Kaoua, 2012). Il était donc possible que les aînés soient peu familiers avec les interfaces de RV, qu'ils soient réfractaires à leur utilisation, qu'ils peinent à les maîtriser et/ou qu'ils ressentent des symptômes adverses à leur contact. Il était également important de s'assurer que la tâche de RV mesurait le construit visé, la mémoire, et que nos deux populations seraient à même de la compléter sans trop de facilité ou trop de difficulté.

En bout de ligne, la tâche de La boutique virtuelle a été exécutée sans obstacle majeur sur le plan de l'utilisation du matériel. De plus, la distribution des scores de performance présentait une bonne variabilité dans les deux populations, indiquant un niveau de difficulté adéquat. Puis, le temps de complétion de La boutique virtuelle n'a pas excédé les 15 minutes. La tâche peut donc s'administrer dans un temps comparable voire plus court que celui nécessaire pour d'autres tâches de mémoire épisodique (p.ex. CVLT-II ; Delis, Kramer, Kaplan, & Ober, 2000, etc.). Puisque l'évaluation cognitive est souvent limitée en termes de temps, tant en recherche qu'en clinique, la courte durée de la tâche de La boutique virtuelle ajoute à la faisabilité de son utilisation dans ces dits contextes. Plus globalement, il semble qu'il soit faisable d'utiliser la RV immersive pour évaluer la cognition chez les personnes jeunes et âgées. Il semble aussi que les personnes âgées tolèrent bien les systèmes comportant un visiocasque HDM tout en utilisant la marche réelle comme mode de navigation.

Ces résultats sont cohérents avec ceux des rares protocoles de recherche s'étant servi avec succès de tâches de RV immersive avec visiocasque chez les individus âgés (Optale et al., 2001 ; Optale et al., 2010 ; Bier et al., 2018). Au-delà de la reproductivité de cette observation, l'étude a démontré que la marche réelle pouvait se voir couplée, avec réussite, à l'utilisation du visiocasque chez les personnes âgées. D'entrée de jeu, la marche réelle avec le visiocasque aurait pu engendrer des problèmes d'équilibre dus à la lourdeur du casque et/ou à l'absence de contact visuel avec la pièce. Il est d'autant plus démontré que réaliser une tâche cognitive en marchant engendre des perturbations de la marche dans le vieillissement (Woollacott & Shumway-Cook, 2002 ; Hollman, Kovash, Kubik, & Linbo, 2007). Tout au plus, il avait été suggéré que la marche sur tapis roulant en contexte de RV non immersive était possible dans une population de personnes âgées saines, avec TCL (Tarnanas et al., 2013) ou atteintes de la maladie de Parkinson (Mirelman et al., 2013 ; Mirelman et al., 2016). À notre connaissance, une seule étude avait utilisé avec succès la marche sur tapis roulant en contexte de RV immersive, le protocole visant la réduction du risque de chute chez des parkinsoniens (Kim, Darakjian, & Finley, 2017). Les présents travaux abondent dans le même sens que ces observations : les participants âgés sont capables de se déplacer dans un environnement virtuel en marchant. Ils vont toutefois plus loin, puisqu'ils ont permis d'observer que les personnes âgées étaient à même de se déplacer en marchant *librement* dans une pièce alors qu'elles sont immergées dans la RV immersive, coupées des stimuli visuels du monde réel.

Toutefois, en regard des participants jeunes, les participants âgés mettaient plus de temps à compléter la tâche de mémoire dans La boutique virtuelle. Bien que cette différence puisse être attribuée à une disparité sur le plan purement mnésique – soit que les personnes âgées prennent plus de temps pour récupérer les items en mémoire – il n'est pas exclu qu'un ralentissement de la marche dû à l'âge soit en cause. Cette possibilité n'est pas vue comme un facteur confondant dans la performance mnésique, puisqu'au contraire, elle reproduirait plutôt la façon dont s'effectue une tâche mnésique en contexte de marche dans la vie réelle des aînés. Il est finalement impératif de rappeler que les participants affirmant présenter des troubles de l'équilibre étaient d'emblée exclus de la recherche, pour des raisons de sécurité. Il n'est donc pas assuré que la présente tâche puisse convenir à l'ensemble de la population vieillissante ou encore aux personnes âgées ayant atteints le stade de démence, chez qui les troubles d'équilibre sont plus fréquents (Allan, Ballard, Burn, & Kenny, 2005). Or, la marche dans La boutique virtuelle paraît convenir chez les personnes âgées saines ainsi que chez celles avec DCS affirmant ne pas présenter de problème d'équilibre.

Ensuite, la RV immersive est associée à la présence fréquente de cybermalaises (Sharples, Cobb, Moody, & Wilson, 2008), certaines études suggérant même l'amplification de ceux-ci dans le vieillissement (Arns & Cerney, 2005). Or, dans une étude récente, notre équipe a démontré que ces symptômes étaient négligeables dans La boutique virtuelle (Corriveau-Lecavalier, Ouellet, Boller, & Belleville, 2018). Spécifiquement, nous avons mis de l'avant que, suite à la complétion de la tâche par des personnes jeunes et âgées, les symptômes globaux de cybermalaises (e.g., inconfort général, maux de tête, nausées, etc.) ne montraient pas d'augmentation significative par rapport à une mesure prise avant l'immersion. De façon intéressante, les personnes âgées ne présentaient pas davantage de symptômes que les jeunes. De la même manière, il ne semble pas que les cybermalaises aient entravé la complétion de la tâche au sein des études de l'article 1. Il est possible que le fait que la tâche soit courte ait limité l'apparition de ces symptômes indésirables (Jaeger & Mourant, 2001). De la même façon, l'exploration active de l'environnement, plutôt qu'une observation passive, a pu contribuer à limiter ces symptômes (Sharples et al., 2008).

Puis, le manque d'aisance des aînés avec le pointeur virtuel représentait un obstacle éventuel à l'accomplissement de la tâche mnésique dans La boutique virtuelle. En effet, des études antérieures supportaient l'idée que certains outils technologiques, tels qu'une souris ou un écran tactile, étaient moins bien maîtrisés par les personnes âgées que par les jeunes (Smith, Sharit, & Czaja, 1999 ; Rogers et al., 2005 ; Findlater et al., 2013). Par ailleurs, l'utilisation du pointeur semblait ici efficace tant chez les jeunes et chez les individus âgés, puisque les niveaux de performance dans La boutique virtuelle, en termes de bonnes réponses, étaient assez élevés dans les deux groupes. Il n'est pas exclu toutefois que les aînés aient effectivement montré moins d'aisance et de précision quant à la manipulation du pointeur virtuel. En effet, le groupe de personnes âgées a mis davantage de temps à effectuer une première sélection d'objet, ce qui pourrait être dû en tout ou en partie à une difficulté à se familiariser avec l'outil de sélection. De plus, les annulations de sélections se sont montrées plus fréquentes chez les aînés. Une interprétation possible de ce phénomène pourrait être que ces derniers peinaient davantage que les jeunes à pointer l'objet qui les intéressait, et ainsi sélectionnaient les mauvais objets, qui devaient alors être « annulés ». Sur ce chapitre, il est connu que le contrôle moteur fin tend à diminuer avec l'âge (Voelcker-Rehage, 2008) ; les résultats présents abondent dans ce sens. Ces observations confirment qu'il était avisé et pertinent d'offrir une option d'annulation des sélections.

Plus largement, le phénomène de la « techno-phobie » était un frein potentiel au succès d'une tâche de RV immersive chez les aînés. Des études suggèrent en effet que la peur de la technologie soit plus fréquente chez les individus âgés, comparativement aux jeunes (Hogan, 2009). Même les personnes âgées qui sont enclines à son usage conservent souvent certaines appréhensions, surtout en lien avec la difficulté à comprendre les instructions d'utilisation (Vaportzis, Clausen, & Gow, 2017). Par ailleurs, dans une étude récente (Corriveau-Lecavalier et al., 2018), notre équipe a montré que la réalisation de La boutique virtuelle était en fait jugée plus motivante que la complétion d'une tâche de mémoire classique, tant par les jeunes que par les personnes âgées. Il est possible que la RV motive les participants à se soumettre aux tâches, en raison de son aspect ludique et proche du quotidien (Plancher et al., 2008). Il semble donc que l'utilisation d'une technologie de RV immersive ne soit pas un frein à la participation à une étude, mais plutôt un avantage. D'abord, le degré de motivation ressentie lors d'une tâche cognitive semble positivement associée à la performance cognitive mesurée (Hess, Popham, Emery, & Elliott, 2012 ; Corriveau-Lecavalier et al., 2018). De surcroît, un haut niveau de motivation face aux tâches expérimentales d'un protocole de recherche diminue fort probablement les risques d'abandon de l'étude en cours de route, si celle-ci comporte plusieurs séances.

En dernier lieu, cette thèse a aussi mis en lumière, par l'entremise de l'article 2, qu'il était faisable d'utiliser la RV immersive en contexte d'intervention dans une population avec DCS. Autrement dit, comme dans l'étude de Optale et ses collaborateurs (2010), un groupe de personnes âgées a été soumis à plusieurs séances de RV immersive et cela sans que des obstacles majeurs soient notés. Il est certain que les présents travaux n'ont pas porté spécifiquement sur les marqueurs de faisabilité de la RV en contexte d'intervention. Or, plusieurs indices témoignent de cette faisabilité, soit le bon déroulement des séances d'exercices en RV, la quasi-absence d'abandons de l'étude en cours d'intervention, et le peu d'abandons des séances en raison de cybermalaises. À cet effet, il faut signaler que trois participants sur 40 ont quand même présenté des symptômes (nausées et/ou vertiges) les empêchant de poursuivre les séances de RV. Dans tous les cas, les symptômes se sont révélés dès la première immersion. Il est donc essentiel de préciser que la présence de cybermalaises, bien que peu fréquente et ne constituant pas un problème majeur dans La boutique virtuelle, se produit chez quelques personnes.

En somme, les résultats de la thèse indiquent clairement qu'une tâche de RV immersive et utilisant la marche réelle comme mode de navigation – telle que La boutique virtuelle – puisse être utilisée tant en contexte d'évaluation que d'intervention cognitive chez les personnes âgées.

5.2.2. Validité

Un des objectifs de la thèse était d'évaluer si La boutique virtuelle présentait une bonne validité de construit, c'est-à-dire si elle évaluait bel et bien la mémoire épisodique en contexte complexe du quotidien. Rappelons que nous avons mis de l'avant que la tâche était modérément reliée à une tâche de mémoire classique, le RL/RI-16, supportant qu'elle évalue bien la mémoire. En revanche, les scores obtenus en RV n'étaient pas corrélés avec le score d'inhibition cognitive du Stroop-Victoria. Cela est plus surprenant étant donné que la tâche demande d'inhiber les stimuli visuels et auditifs non pertinents à la tâche. Une explication possible est que les participants aient pu contourner une difficulté d'inhibition via l'utilisation de stratégies compensatoires dans La boutique virtuelle. Par exemple, il leur était possible de détourner le regard d'un stimuli visuel pour ne pas se laisser distraire. Conséquemment, il est toujours possible que La boutique virtuelle implique effectivement des processus d'inhibition, mais qu'ils n'aient pu être mesurés. Rappelons aussi que comme la corrélation avec le RL/RI-16 n'était que modérée, il demeure suggéré que d'autres fonctions cognitives soient impliquées dans La boutique virtuelle. Cet élément peut d'ailleurs être en faveur de la validité écologique de la tâche, puisqu'il est attendu qu'une tâche mnésique dans la vie de tous les jours soit complexe et implique plusieurs fonctions cognitives.

Dans un deuxième temps, l'obtention de rendements significativement meilleurs chez les jeunes, soit sur le plan du nombre de bonnes réponses, est un autre signe de validité de construit. En effet, la différence de performance entre les personnes jeunes et âgées est attendue au sein d'une tâche de mémoire épisodique (Park et al., 2002). La capacité à distinguer deux populations supposées différentes cognitivement à l'aide d'une tâche cognitive en RV a déjà été démontrée par plusieurs études. D'abord, les personnes jeunes et âgées ont pu être distinguées par des tâches virtuelles qui mesuraient les fonctions exécutives (Craik & Bialystok, 2006 ; Tarnanas et al., 2015), la mémoire (Farrimond et al., 2006), les capacités fonctionnelles (Atkins et al., 2015) ou la capacité à accomplir des activités quotidiennes (Rand, Katz, & Weiss, 2007). Également, des tâches en RV visant à évaluer les fonctions exécutives (Werner, Rabinowitz, Klinger, Korczyn, & Josman, 2009), la mémoire épisodique (Plancher et al., 2012), l'apprentissage spatial (Cushman et al., 2008), les capacités fonctionnelles (Tarnanas et al., 2013) ou la capacité à accomplir des activités quotidiennes (Rizzo et al., 1997 ; Rizzo et al., 2001 ; Zygouris et al., 2014 ; Allain et al., 2014) ont pu distinguer les personnes âgées saines des personnes avec TCL, ou ont réussi à différencier les personnes avec TCL de celles présentant une MA. Au-delà d'un appui à la validité des tâches, ces résultats supportent l'éventualité de créer des outils de RV à visée diagnostique. Nous savons que par exemple, plusieurs personnes avec plainte mnésique offrent une cognition intacte. Or, il est possible que celles-ci présentent des déficits indétectables par les outils actuels. Les épreuves neuropsychologiques en RV pourraient s'avérer d'une complexité suffisante pour mettre au jour ceux-ci et mieux distinguer des autres les individus qui ont plus de risques de se trouver dans une phase préclinique de la MA.

Le fait que le rendement à La boutique virtuelle soit relié à un score de plainte mnésique en contexte de magasinage suggère que la tâche reflète le fonctionnement mnésique quotidien. Nous reproduisons aussi les résultats de précédentes études qui ont mis de l'avant que des tests virtuels de mémoire épisodique étaient corrélés à des questionnaires auto-rapportés mesurant la performance mnésique dans la vie de tous les jours (Potvin et al. 2011 ; Plancher et al., 2010). Or, La boutique virtuelle semble être reliée spécifiquement à la capacité mnésique auto-rapportée en contexte d'achats quotidiens ; elle n'est pas liée à l'évaluation globale de la mémoire dans la vie de tous les jours. Ainsi, il appert que notre tâche puisse refléter des habiletés mnésiques très collées au scénario virtuel.

5.3. Transfert d'une intervention mnésique et apport de la RV

Un des apports de la thèse a été de mettre de l'avant différents types d'effets de transfert d'un entraînement à la méthode des lieux, soit des transferts de contenu et de contexte. Réitérons que le transfert de contenu se produit lorsqu'un apprentissage permet d'améliorer une habileté non directement visée par l'entraînement, mais partageant des processus cognitifs communs avec la ou les tâches entraînées. Le transfert de contexte, de son côté, survient lorsque l'apprentissage d'une stratégie ou un comportement réalisé dans un contexte particulier est appliqué avec succès dans un nouveau contexte. La présente thèse a majoritairement focalisé sur le transfert de contexte vers la vraie vie, via l'utilisation de la RV, mais des transferts des deux types ont été mis en évidence.

Un premier transfert de contenu a été montré dans l'article 2. Celui-ci a été évalué grâce à une mesure de rappel de mots dans laquelle la modalité de présentation (auditive) différait de celle utilisée lors de l'entraînement (visuelle). Les résultats ont démontré que suite à trois séances d'intervention (du PRÉ au POST 3), les participants avaient une meilleure performance sur cette tâche, attestant du transfert de contenu, plus précisément de modalité. L'apprentissage de la méthode des lieux réalisé avec des mots présentés visuellement peut donc se généraliser et s'appliquer ensuite à du matériel verbal présenté autrement. Bien qu'il n'en demeure qu'un transfert de contenu, ce constat est très intéressant en regard du transfert éventuel dans la vie de tous les jours. En effet, au quotidien, les informations verbales que nous devons retenir sont souvent présentées auditivement, que ce soit lors d'une conversation avec autrui, lors de l'écoute d'un message téléphonique, etc. Notre résultat est d'autant plus intéressant que le transfert de modalité dans le cadre d'un entraînement cognitif n'a pas été souvent étudié de façon spécifique. Dans la littérature, Lussier et al. (2012) se trouvent parmi les seuls à s'être focalisés particulièrement sur le transfert de modalité des stimuli. Leur entraînement attentionnel en contexte de double-tâche utilisait deux tâches de discrimination visuelle concourantes : indiquer le sens d'une flèche et identifier la couleur d'un carré. Après l'entraînement avec ces exercices, le coût attentionnel avait diminué lors de la complétion d'une double-tâche auditive, consistant à discriminer la provenance d'un son (droite ou gauche) tout en identifiant un mot entendu (go ou stop). Pour ce qui est de la méthode des lieux, son apprentissage ainsi que l'évaluation de son efficacité se fait habituellement avec des mots présentés à l'écrit (e.g., Yesavage et al., 1984b ; Belleville et al., 2006 ; 2018). En revanche, plusieurs articles ne décrivent pas précisément le contenu exact de leurs exercices de mémoire, et il est ainsi difficile de statuer sur la présence ou non d'un transfert de modalité post-intervention. Par exemple, il y a fort à penser que l'étude ACTIVE (Ball et al., 2002) révèle un transfert de modalité, puisque leur intervention mnésique était supportée par un manuel écrit (Jobe et al., 2001) et que des hausses de rendement ont été mesurées par la suite sur des tâches de rappel de mots présentés auditivement.

Un second transfert de contenu est survenu dans le cadre de l'article 3. Celui-ci a été évalué à l'aide d'une tâche de rappel de mots effectuée en contexte de bruit verbal. Les participants se sont améliorés sur cette tâche suite à trois séances d'apprentissage de la méthode des lieux (PRÉ 1 au PRÉ 2). Les participants ont aussi vu l'effet délétère du bruit disparaître après la deuxième phase d'entraînement de la méthode des lieux (PRÉ 2 au POST), peu importe le groupe (MÉMOIRE+MÉMOIRE vs MÉMOIRE+ATTENTION). Il apparaît donc que la méthode des lieux à elle seule ait permis cet effet de transfert. Cette généralisation de l'amélioration de la mémoire d'un contexte silencieux à bruyant est en soi une découverte importante. En effet, une personne âgée doit souvent utiliser sa mémoire dans des lieux publics où il y a du bruit. Par exemple, à l'épicerie, il faut se rappeler de sa liste de courses, tout en faisant fi des conversations des autres clients, de la musique ambiante, du son des caisses, etc. Ces résultats sont un premier pas indiquant que, même confrontées à ce genre de bruit potentiellement distrayant, les personnes âgées pourraient utiliser avec succès une stratégie mnésique précédemment apprise. Ensuite, le fait que l'effet délétère du bruit ait complètement disparu suite à l'apprentissage de la méthode des lieux est un constat des plus encourageants. Rappelons que la difficulté à mémoriser dans des contextes exigeants sur le plan attentionnel est l'une des plaintes mnésiques les plus fréquentes chez personnes âgées (Langlois & Belleville, 2014). Et nous pourrions donc diminuer, voire éliminer leur sensibilité au bruit par une intervention cognitive axée sur l'imagerie mentale visuelle. En effet, nous croyons que l'imagerie visuelle puisse favoriser un encodage visuel de l'information, même si elle est présentée verbalement au départ. Ainsi, au lieu que les mots à apprendre soit soumis à une distraction verbale concurrente, le participant se retrouve à encoder des images visuelles, qui sont moins vulnérables aux distracteurs verbaux. En appuie à cette théorie, il a été montré que la vulnérabilité aux distractions liée à l'âge est plus susceptible de se manifester dans des paradigmes de type « uni-modalité » que dans ceux de type « multi-modalités » (voir Guerreiro, Murphy, & Van Gerven, 2010, pour une revue).

Le transfert de contexte, i.e., dans des situations proches du quotidien, constituait le focus principal de la présente thèse. Celui-ci a été plus particulièrement étudié dans l'article 2. Il était mesuré par l'entremise de deux tâches de RV immersive (La boutique virtuelle et La promenade en voiture virtuelle) et d'un questionnaire auto-rapporté. Le premier effet de transfert de contexte objectivé est celui sur La boutique virtuelle. Celui-ci évaluait la capacité à mémoriser une liste de produits, à les retrouver et à les sélectionner dans un magasin virtuel, tout en s'y déplaçant en marchant. Nous avons mesuré une amélioration de la performance de mémoire suite à trois séances d'intervention (du PRÉ au POST 1). Il est ainsi supposé que l'apprentissage de la méthode des lieux puisse se généraliser à des tâches complexes et proches du quotidien. Par contre, cette tâche demeure proche de celle utilisée lors de l'entraînement. Effectivement, les deux groupes (RV+ et RV-) ont réalisé des exercices d'achats de produits en marchant dans l'environnement de La boutique virtuelle. En ce sens, il s'agit plutôt d'un transfert de contexte assez proche de l'entraînement. Ensuite, il y a eu un transfert sur La promenade en voiture virtuelle. Cette tâche demandait de mémoriser une liste de mots tout en réalisant une tâche de copilote en voiture, celle-ci consistant à détecter des panneaux autoroutiers. Nous avons mesuré une amélioration de la performance de mémoire suite à trois séances d'intervention (du PRÉ au POST 1). Il a aussi été montré que les gains obtenus suite à l'entraînement sont corrélés au gain obtenu à La promenade en voiture virtuelle, suggérant un transfert réel des apprentissages et non un effet de pratique (i.e., test-retest). Cette tâche de RV est nouvelle et diffère grandement de celle utilisée lors de l'entraînement : les participants s'y déplacent de façon passive (plutôt qu'active en marchant), le matériel à mémoriser est strictement verbal et présenté auditivement (plutôt qu'à l'écrit avec support imagé) et une tâche concourante doit être réalisée. De ce fait, cette amélioration représente un transfert de contexte plutôt éloigné de l'entraînement. Ce résultat est très encourageant, car dans la vie de tous les jours, les différentes situations où la mémoire est sollicitée diffèrent grandement les unes des autres. Le but d'une intervention mnésique vise précisément ce genre de transfert, du laboratoire à des tâches tout à fait différentes exécutées dans le cadre d'une situation de la vie quotidienne. De plus la mémorisation en contexte de double-tâche est assez fréquente dans la vie de tous les jours.

Une dernière mesure de transfert de contexte était un questionnaire auto-rapporté mesurant la capacité de mémoire dans différentes situations du quotidien. L'entraînement n'a finalement produit aucun changement sur celui-ci. Nous avons donc reproduit les résultats de plusieurs études qui n'ont pas eu d'effet sur ce type de mesure (Ball et al., 2002 ; Belleville et al., 2018 ; Kinsella et al., 2009). Il est utile de rappeler que ces questionnaires n'évaluent pas formellement la performance de mémoire, mais bien les *pensées* ou les *croyances* qu'ont les individus par rapport à leur propre performance mnésique dans la vie de tous les jours. Il a été précédemment montré que les scores de ces questionnaires n'étaient souvent que modérément reliés à la performance réelle de mémoire (voir Herrmann, 1982, pour une revue). Il semble que l'auto-évaluation qu'une personne fait de sa mémoire soit en partie liée à divers facteurs, tels que l'âge, la confiance en sa mémoire ou la susceptibilité aux oublis en situation de stress (Herrmann, 1982), etc. De plus, l'auto-évaluation de la mémoire chez les personnes âgées paraît être stable dans le temps (McDonald-Miszczak, Hertzog, & Hultsch, 1995 ; Weaver Cargin et al., 2008). Ainsi, il est possible qu'un changement se produisant dans la performance mnésique suite à une intervention ne soit tout simplement pas reflété dans ces mesures, ou encore que les gains soient limités. Une contribution des travaux de cette thèse est définitivement d'avoir mis de l'avant que le transfert de contexte pouvait se produire sur des mesures de RV objectives et représentantes du quotidien, alors même que les questionnaires ne reflétaient pas ce transfert. Nous appuyons les tout récents résultats de Bier et al. (2018), qui avaient montré ce phénomène, mais suite à une intervention sur le contrôle de l'attention. Tous ces résultats pointent donc dans un sens : les évidences jusqu'ici limitées en matière de transfert au quotidien pourraient relever d'un manque de mesures objectives et écologiques pour le détecter. La RV immersive nous apparaît maintenant comme un outil de choix pour créer ce type de mesure.

5.4. L'effet de la dose d'entraînement

Cette thèse permettait également d'étudier l'effet de la dose d'entraînement sur les différents marqueurs d'efficacité et de transfert. Un contraste intéressant s'est imposé entre ces deux études. D'abord, il semble que trois séances d'une heure soient suffisantes pour créer des effets de transfert de modalité et de contexte au sein de l'article 2. Trois séances supplémentaires n'ont pas eu d'impact subséquent. En revanche, si l'apprentissage de la méthode des lieux a mené à une première amélioration sur une tâche dans le bruit dans l'article 3, les trois séances supplémentaires ont amplifié les effets, jusqu'à faire disparaître l'effet délétère du bruit. Le nombre de séances d'intervention nécessaires à l'obtention d'un effet de transfert pourrait donc varier selon la mesure de transfert utilisée ou l'effet de transfert visé. Dans une méta-analyse, Gross et al. (2012) démontraient pourtant que les gains suite à une intervention mnésique n'étaient pas influencés par le nombre d'heures d'entraînement. Cependant, ce résultat a pu être influencé par le fait que la durée totale d'une intervention n'est pas le seul facteur à prendre en considération. En effet, d'autres variables non examinées telles que la fréquence (Gates et al., 2011) et la durée des sessions (Verhaeghen et al., 1992) ont été précédemment identifiées comme des modérateurs des effets des interventions mnésiques. Peut-être également que les effets de la dose peuvent différer selon s'il s'agit d'une mesure proximale de l'entraînement ou d'une mesure de transfert. Nos résultats soutiennent pour leur part qu'en matière de transfert, la dose d'entraînement peut influencer les effets obtenus. Dans certains cas, le « sur-apprentissage » d'une stratégie pourrait permettre d'optimiser ses effets dans des tâches différentes de celles entraînées.

5.5. Bénéfices associés à l'enrichissement d'une intervention mnésique avec des exercices près du quotidien

Un des objectifs de ce travail était de tester si le fait d'enrichir une intervention mnésique avec des exercices plus près de la vie quotidienne pouvait être efficace et/ou améliorer les effets de transfert chez les personnes avec DCS. Cela a été fait en combinant la méthode des lieux à de la pratique en RV (Article 2) ou à un entraînement attentionnel (Article 3). Malheureusement, l'ajout de ces conditions d'entraînement n'a pas mené à des gains cognitifs supérieurs, ni à un meilleur transfert. Dans le premier cas, l'ajout d'exercices de RV n'a pas permis d'augmenter les effets de transfert de contexte, que ceux-ci soient mesurés subjectivement ou objectivement avec des tâches proches du quotidien. Dans le deuxième cas, la complétion des exercices mnésiques en situation d'entraînement à l'inhibition auditive n'a pas permis d'améliorer la performance mnésique dans le bruit. Ces deux études étaient les premières, à notre connaissance, à tenter d'enrichir l'entraînement à la méthode des lieux avec des exercices à valeur écologique en RV immersive ou en contexte de bruit ambiant. La force de ces travaux réside sans contredit dans leur design. En effet, il a été choisi de requérir à l'utilisation d'une randomisation en deux conditions, où une condition enrichie est comparée à une condition d'entraînement similaire, mais non enrichie. Ainsi, les protocoles rendaient possible l'isolation des effets propres à l'enrichissement de l'entraînement. L'absence d'effets propres aux conditions d'enrichissement montrée ici est plutôt contraire à la littérature, qui indique plutôt que l'utilisation de méthodes multiples maximise les bénéfices d'un entraînement mnésique chez les personnes âgées (Verhaeghen et al., 1992 ; Gross et al., 2012). Nos résultats soulèvent des questionnements ; il apparaît impératif de s'interroger sur les facteurs qui pourraient expliquer ceux-ci, ce que nous faisons dans la prochaine section.

Une première hypothèse pouvant rendre compte de l'absence d'effet de l'enrichissement en RV est la trop courte durée des exercices de RV, soit seulement 10 minutes par séance, sur six séances. En effet, les études d'entraînement cognitif en RV non immersive ayant montré des effets positifs ont fait usage d'interventions en RV beaucoup plus longues. Par exemple, Gamito et al. (2017) ont mis en lumière des améliorations neuropsychologiques sur les plans mnésique et attentionnel dans une population clinique suite à des sessions d'entraînement de 60 minutes, à raison de deux à trois fois par semaine, sur quatre à six semaines. Un peu comme la nôtre, leur intervention était basée sur la pratique de tâches cognitives dans des scénarios virtuels (mais non immersif) près du quotidien. De la même façon, pour en arriver à des bénéfices cognitifs supérieurs par rapport à une intervention classique, les participants avec TCL de Man et al. (2012) complétaient dix séances de 30 minutes en RV non immersive. La seule intervention en RV immersive montrée efficace dans le vieillissement utilisait pour sa part des séances de 15 minutes en RV, chacune suivie d'une discussion de 15 minutes sur l'immersion (Optale et al., 2010), accordant donc 30 minutes à l'expérience de RV. En somme, l'analyse de ces études suggère que la présente intervention pourrait ne pas avoir eu les effets escomptés en raison d'une trop faible dose d'entraînement en RV. Rappelons que le choix de requérir à de courtes immersions visait à diminuer les risques d'apparition de cybermalaises chez les participants (Jaeger & Mourant, 2001). Dans une prochaine étude, les doses d'exercices en RV pourraient maintenant être plus grandes, afin de tester si des effets de transfert vont ainsi se manifester. Une autre cause possible à l'absence d'effet de la condition RV+ est le fait que l'entraînement à la méthode des lieux en lui-même mène déjà à des effets de transfert, et que ceux-ci ne peuvent que peu ou pas être améliorés par l'ajout d'exercices en RV. Aussi, la possibilité que cette technique soit superflue dans un contexte où l'intervention de base est elle-même très performante doit être envisagée. Enfin, il n'est pas exclu que les effets de la condition RV+ aient été présents mais que ceux-ci n'aient pas été capturés par nos mesures de transfert. D'abord, l'utilisation d'une mesure auto-rapportée telle que le MMQ-Capacité se solde bien souvent par une absence d'effet suite à une intervention mnésique (Ball et al., 2002), et ce même suite à une intervention en RV (Man et al., 2012). Ensuite, les deux tâches de transfert en RV, même bien construites pour mesurer les effets de la méthode de lieux dans la vraie vie, pourraient ne pas avoir été assez sensibles pour détecter des différences fines entre les deux conditions d'entraînement.

L'ajout d'exercices dans le bruit verbal n'a pas non plus permis de mener à une meilleure mémorisation dans le bruit. Notons ici encore que la méthode des lieux en elle-même a amélioré la mémorisation dans le bruit, jusqu'à faire disparaître l'effet délétère du bruit. Ainsi, si le bruit ne gênait plus le rendement mnésique, les effets d'une condition d'entraînement dans le bruit (MÉMOIRE+ATTENTION) se voyaient difficiles à mettre en évidence. La tâche d'efficacité utilisée a aussi pu manquer de sensibilité, ou encore cette condition d'enrichissement n'était pas un bon choix pour promouvoir la mémorisation dans le bruit.

En somme, il apparaît que la méthode des lieux mène déjà à des effets de transfert, qu'ils soient sur des tâches en RV ou sur une tâche mnésique dans le bruit. Conséquemment, il était d'autant plus difficile de mettre de l'avant les impacts des différents exercices d'enrichissement testés. L'ensemble de ces résultats mettent de l'avant l'immense défi associé à la construction d'interventions efficaces. Un constat s'impose toutefois : la méthode des lieux est sans contredit une stratégie à intégrer au sein d'une intervention multifactorielle chez les personnes âgées ; tout indique qu'elle est un ingrédient actif de l'intervention, particulièrement auprès d'une population avec DCS.

5.6. Implications cliniques de la thèse

Notre travail confirme qu'une mesure cognitive en RV immersive peut être faisable et valide chez les jeunes, mais aussi chez les personnes âgées. Tout indique donc que la RV immersive pourrait éventuellement représenter un nouvel outil de mesure de la cognition en neuropsychologie clinique auprès de ces deux populations. Au-delà de nos résultats, plusieurs études supportent que diverses populations cliniques pourraient aussi bénéficier de ce type d'outil afin de mieux caractériser leurs déficits cognitifs. À titre d'exemple, Potvin et al. (2011) ont montré la validité et la sensibilité d'un scénario présenté sur ordinateur pour évaluer la mémoire prospective chez des personnes ayant subi un traumatisme crânien. De même, des auteurs suggèrent qu'un labyrinthe virtuel peut être sensible aux déficits spatiaux dans la schizophrénie (Weniger & Irle, 2008 ; Spieker, Astur, West, Griego, & Rowland, 2012). De façon intéressante, les outils en RV pourraient même s'avérer plus sensibles que les mesures neuropsychologiques classiques (Plancher et al., 2010). De même, nos travaux suggèrent que les mesures cognitives en RV pourraient être plus sensibles que les questionnaires pour caractériser la cognition dans la vie quotidienne.

Maintenant, est-ce que ce type d'outil pourrait être utilisé dans le milieu de la santé, pour aider à établir des diagnotics cliniques ? Il y a beaucoup à faire encore avant d'en arriver là. En effet, il faudra voir si au-delà de la détection d'une différence de moyennes entre deux groupes cliniques sur le plan cognitif (e.g., Zygouris et al., 2014), les outils en RV sont assez sensibles pour identifier des déficits à un niveau individuel. L'établissement de normes sur de grands échantillons sera également une étape nécessaire.

Cette thèse montre de même qu'il est possible d'améliorer la mémoire épisodique des personnes âgées avec DCS à l'aide d'un entraînement mnésique de type stratégique, et surtout que ces gains sont transférés dans des tâches près du quotidien. Ces résultats suggèrent que les entraînements mnésiques atteignent leur cible ultime, soit l'amélioration de la mémoire des individus au quotidien. Ce constat encourageant soutient la pertinence d'implanter des programmes d'entraînement cognitif en milieu clinique, surtout pour des personnes avec plainte de mémoire. En effet, la prévalence de la plainte mnésique est grande au sein de la population âgée (Jonker et al., 2000). La prévention des pertes de mémoire serait même la plus grande priorité de santé des femmes canadiennes de 65 ans et plus (Tannenbaum, Mayo, & Ducharme, 2005). Or, jusqu'à présent, le système de santé avait peu à leur offrir. La quasi absence d'abandons dans nos études intervention suggèrent que ces individus sont prêts à s'engager dans des programmes d'intervention et à les compléter jusqu'au bout. De plus, nous avons montré qu'un petit nombre de séances est suffisant pour générer des effets dans des tâches représentatives du quotidien. Ainsi, il est suggéré que même de courts programmes pourraient être utiles. Cette information prend toute son importance lorsque l'on tient compte du fait que les ressources sont souvent limitées dans les milieux cliniques, soit en termes d'argent ou de personnel, ce qui peut rendre difficile l'implantation de longs programmes d'intervention.

Même s'il n'a pas été établi qu'une intervention enrichie d'exercices en RV immersive peut favoriser le transfert, nos recherches démontrent que les séniors acceptent de participer à ce type d'exercices et que ceux-ci peuvent se dérouler sans obstacle majeur. Cette information est importante étant donné que nous sommes aux premiers balbutiements de l'intervention en RV immersive. Ainsi, nos travaux encouragent la création de nouveaux programmes d'intervention en RV immersive chez les personnes âgées. Ils incitent également à se préoccuper tout particulièrement de la dose d'intervention prodiguée en RV lors de la conception de tels programmes.

5.7. Limites de la thèse

Il importe maintenant de décrire les limites associées aux travaux de cette thèse. Une des limites les plus importantes réside en l'absence d'un groupe de contrôle sans contact au sein des deux études d'intervention (article 2 et 3). Ainsi, il est impossible de distinguer formellement les effets dus aux interventions de ceux dus à un simple effet de pratique des mesures d'efficacité et de transfert. Ce choix méthodologique relève du fait que le but principal des deux études d'intervention était de comparer une condition de mémoire « enrichie » à l'une non enrichie. En effet, on connaissait déjà l'efficacité de la méthode des lieux. Or, comme dans les deux études, aucune différence n'a été trouvée entre les deux conditions, nous nous sommes retrouvés à étudier les effets de l'intervention commune, l'apprentissage de la méthode des lieux. Une prochaine étude du genre devrait donc inclure un groupe de contrôle sans contact afin de pouvoir bien valider la nature des effets de l'intervention principale.

Une seconde limite est le fait que nous n'ayons pas étudié les effets de maintenance de nos interventions. Il aurait été intéressant de mesurer si les effets de transfert étaient maintenus un mois, six mois ou un an plus tard. De même, comme la population avec DCS présente des risques accrus de développer une démence, il aurait été pertinent d'étudier si l'intervention permettait de prévenir ou de retarder un déclin cognitif futur par rapport à un groupe de participants DCS non entraînés.

Ensuite, mentionnons que les échantillons de participants recrutés pour les études d'intervention comportaient majoritairement des femmes. Il se peut donc que les présents résultats ne puissent pas se généraliser à une population d'hommes. Il est fréquent que les femmes soient surreprésentées au sein des études d'intervention. Par exemple, l'échantillon de l'étude ACTIVE comportait 77% de femmes. Des études futures devront donc recruter des échantillons plus équilibrés afin de distinguer si les effets des interventions sont différents selon le sexe. Puis, les échantillons de participants recrutés pour les études d'intervention étaient en moyenne assez jeunes, malgré qu'ils soient qualifiés de personnes « âgées ». L'inclusion de personnes âgées plus jeunes (55 ans et plus) que dans les études habituelles sur le vieillissement (i.e. 65 ans et plus) visait à bien cibler notre population d'intérêt, les personnes avec DSC. Comme le DSC précède le TCL et la MA, celui-ci se présente forcément à un plus jeune âge. Ceci-dit, les présents résultats pourraient ne pas se généraliser à une population plus âgée de personnes avec DSC. Dans la même veine, les deux études d'intervention de cette thèse comportaient de petits échantillons. Dans le cas où des effets de petites tailles auraient été présents en lien avec les différences entre les groupes, il est possible que nous n'ayons pas pu les détecter en raison d'un manque de puissance statistique.

Une certaine limite des études décrites dans les articles 1 et 2 – ceux-ci impliquant des tâches de RV, plus précisément La boutique virtuelle – relève du fait qu'ils n'incluent pas de mesures formelles quant au *sentiment de présence* et à la *propension à l'immersion*. Le sentiment de présence, qui réfère à l'impression subjective de se trouver réellement dans l'environnement virtuel, peut influencer la performance lors d'une tâche réalisée dans cet environnement (Witmer & Singer, 1998). Or, cette variable n'a pas été utilisée dans les présents articles en raison du fait qu'elle a été analysée en lien avec La boutique virtuelle dans un article précédent (voir l'annexe 5, Corriveau-Lecavalier et al., 2018). Pour ce qui est de la propension à l'immersion, soit la capacité à s'immerger dans un univers fictif, elle gagnerait à être mesurée dans un article futur. En effet, cet élément est susceptible d'influencer le sentiment de présence (Witmer & Singer, 1998).

Enfin, nous devons souligner que l'évaluation de la validité écologique de La boutique virtuelle au sein de l'article 1 a été réalisée à l'aide d'un questionnaire auto-rapporté, une mesure subjective et influencée par le jugement. Nous ne pouvons donc pas certifier que la tâche reflète effectivement le fonctionnement de la mémoire dans une tâche réelle d'achat de produits. Cette limite soulève d'ailleurs un défi de taille dans la validation des tâches cognitives de RV, c'est-à-dire qu'il est complexe de mesurer leur relation exacte avec une tâche similaire réalisée dans le monde réel. D'ailleurs, ce dernier point soulève une dernière limite en lien avec les mesures de transfert en RV utilisées dans le cadre de l'article 2. Bien que celles-ci soient conçues pour refléter des situations complexes du quotidien des personnes âgées, elles demeurent des scénarios artificiels et standardisés. Il n'est donc pas certain qu'une amélioration sur ces mesures puisse refléter une amélioration similaire au quotidien.

5.8. Perspectives futures

La RV est une technologie qui a fait des pas de géants au cours des dernières décennies, et même depuis les premiers balbutiements des travaux de cette thèse. D'abord, les systèmes relèvent d'ordinateurs qui sont beaucoup plus performants, offrant des environnements plus réalistes. Ensuite, la RV devient de plus en plus accessible. Par exemple, il est maintenant possible d'utiliser des lunettes de RV avec son téléphone intelligent (Minocha, Tudor, & Tilling, 2017). L'avènement de ces nouvelles technologies mènent à penser que la RV immersive puisse être utilisée à grande échelle pour la mesure des fonctions cognitives dans un futur proche, même en milieu clinique. En effet, des outils à visée diagnostique pourraient être éventuellement développés. Pour ce qui est de son utilisation en intervention cognitive, la RV immersive devra encore faire ses preuves. Il y a cependant fort à penser que les études d'intervention se multiplieront au cours des prochaines années.

Pour ce qui est des interventions cognitives dans le DCS, nos travaux suggèrent que cette population répond bien à l'entraînement de la mémoire et que leurs apprentissages peuvent se transférer dans des situations proches du quotidien. Il importera dans le futur de poursuivre les études d'intervention dans ce stade très précoce de la MA, afin de voir si l'entraînement peut prévenir ou retarder un éventuel déclin cognitif et/ou maintenir l'autonomie fonctionnelle des individus à long terme.

Une avenue intéressante à étudier dans de futures études sera finalement de répondre à la question suivante : quelles sont les caractéristiques des participants qui répondent le mieux à l'intervention cognitive? Par exemple, les participants dans nos études d'intervention présentaient en moyenne un niveau d'éducation assez élevé, autour de 15 années de scolarité. Il serait donc pertinent d'explorer si la réponse à l'entraînement diffère chez un échantillon moins scolarisé. De même, les participants entraînés étaient assez « jeunes » pour une étude chez les personnes âgées, avec une moyenne autour de 67 ans. Est-ce que les résultats diffèrent selon l'âge au sein même d'une population d'aînés? La question demeure non élucidée, puisque certaines études ont montré que oui (Verhaeghen et al., 1992) alors que d'autres ont statué que non (Gross et al., 2012). Mieux comprendre qui répond bien aux interventions cognitives pourrait éventuellement permettre une prochaine étape : adapter les interventions pour les individus qui n'en bénéficient pas actuellement.

Bibliographie

Adam, S., Van der Linden, M., Ivanoiu, A., Juillerat, A. C., Bechet, S., & Salmon, E. (2007). Optimization of encoding specificity for the diagnosis of early AD: The RI-48 task. *Journal of Clinical and Experimental Neuropsychology, 29*(5), 477–487. doi:10.1080/13803390600775339

Albert, M. S., DeKosky, S. T., Dickson, D., Dubois, B., Feldman, H. H., Fox, N. C., . . . Petersen, R. C. (2011). The diagnosis of mild cognitive impairment due to Alzheimer's disease: Recommendations from the National Institute on Aging-Alzheimer's Association workgroups on diagnostic guidelines for Alzheimer's disease. *Alzheimer's & Dementia, 7*(3), 270–279. doi:10.1016/j.jalz.2011.03.008

Allain, P., Foloppe, D. A., Besnard, J., Yamaguchi, T., Etcharry-Bouyx, F., Le Gall, D., . . . Richard, P. (2014). Detecting everyday action deficits in Alzheimer's disease using a nonimmersive virtual reality kitchen. *Journal of the International Neuropsychological Society, 20*(05), 468–477. doi:10.1017/S1355617714000344

Allan, L. M., Ballard, C. G., Burn, D. J., & Kenny, R. A. (2005). Prevalence and severity of gait disorders in Alzheimer's and non-Alzheimer's dementias. *Journal of the American Geriatrics Society*, *53*(10), 1681–1687. doi:10.1111/j.1532-5415.2005.53552.x

Ally, B. A., Gold, C. A., & Budson, A. E. (2009). An evaluation of recollection and familiarity in Alzheimer's disease and mild cognitive impairment using receiver operating characteristics. *Brain and Cognition, 69*(3), 504–513. doi:10.1016/j.bandc.2008.11.003

Alzheime'Ms Association. (2017). 2017 Alzheimer's disease facts and figures. *Alzheimer's & Dementia*, *13*(4), 325–373. doi:10.1016/j.jalz.2017.02.001

Amariglio, R. E., Becker, J. A., Carmasin, J., Wadsworth, L. P., Lorius, N., Sullivan, C., . . . Johnson, K. A. (2012). Subjective cognitive complaints and amyloid burden in cognitively normal older individuals. *Neuropsychologia*, *50*(12), 2880–2886. doi:10.1016/j.neuropsychologia.2012.08.011

American Psychiatric Association. (2013). Diagnostic and statistical manual of mental disorders (5th ed.). Arlington, VA: American Psychiatric Publishing.

Amieva, H., Le Goff, M., Millet, X., Orgogozo, J. M., Pérès, K., Barberger-Gateau, P., . . . Dartigues, J. F. (2008). Prodromal Alzheimer's disease: successive emergence of the clinical symptoms. *Annals of Neurology, 64*(5), 492–498. doi:10.1002/ana.21509

Anderson, N. D., Ebert, P. L., Jennings, J. M., Grady, C. L., Cabeza, R., & Graham, S. J. (2008). Recollection- and familiarity-based memory in healthy aging and amnestic mild cognitive impairment. *Neuropsychology*, *22*(2), 177–187. doi:10.1037/0894-4105.22.2.177

Anschutz, L., Camp, C. J., Markley, R. P., & Kramer, J. J. (1985). Maintenance and generalization of mnemonics for grocery shopping by older adults. *Experimental Aging Research, 11*(3), 157–160. doi:10.1080/03610738508259180

Arns, L. L., & Cerney, M. M. (2005). The relationship between age and incidence of cybersickness among immersive environment users. *IEEE Proceedings. VR 2005. Virtual Reality,* 267–268.

Atkins, A. S., Stroescu, I., Spagnola, N. B., Davis, V. G., Patterson, T. D., Narasimhan, M., . . . Keefe, R. S. E. (2015). Assessment of age-related differences in functional capacity using the Virtual Reality Functional Capacity Assessment Tool (VRFCAT). *The Journal of Prevention of Alzheimer's Disease, 2*(2), 121–127. doi:10.14283/jpad.2015.61.

Ball, K., Berch, D. B., Helmers, K. F., Jobe, J. B., Leveck, M. D., Marsiske, M., . . . Unverzagt, F. W. (2002). Effects of cognitive training interventions with older adults: A randomized controlled trial. *The Journal of the American Medical Association, 288*(18), 2271–2281. doi:10.1001/jama.288.18.2271

Barker, A., Prior, J., & Jones, R. (1995). Memory complaint in attenders at a self-referral memory clinic: The role of cognitive factors, affective symptoms and personality. *International Journal of Geriatric Psychiatry*, *10*(9), 777–781. doi:10.1002/gps.930100908

Barnes, D. E., Yaffe, K., Belfor, N., Jagust, W. J., DeCarli, C., Reed, B. R., & Kramer, J. H. (2009). Computer-based cognitive training for mild cognitive impairment: results from a pilot randomized, controlled trial. *Alzheimer Disease and Associated Disorders, 23*(3), 205–210. doi:10.1097/WAD.0b013e31819c6137

Barnett, S. M., & Ceci, S. J. (2002). When and where do we apply what we learn? A taxonomy for far transfer. *Psychological Bulletin*, *128*(4), 612–637. doi:10.1037//0033-2909.128.4.612

Bassett, S. S., & Folstein, M. F. (1993). Memory complaint, memory performance, and psychiatric diagnosis: A community study. *Journal of Geriatric Psychiatry and Neurology*, *6*(2), 105–111. doi:10.1177/089198879300600207

Bélanger, S., & Belleville, S. (2009). Semantic inhibition impairment in mild cognitive impairment: A distinctive feature of upcoming cognitive decline? *Neuropsychology, 23*(5), 592. doi:10.1037/a0016152

Bélanger, S., Belleville, S., & Gauthier, S. (2010). Inhibition impairments in Alzheimer's disease, mild cognitive impairment and healthy aging: Effect of congruency proportion in a Stroop task. *Neuropsychologia, 48*(2), 581–590. doi:10.1016/j.neuropsychologia.2009.10.021

Bellassen, V., Iglói, K., de Souza, L. C., Dubois, B., & Rondi-Reig, L. (2012). Temporal order memory assessed during spatiotemporal navigation as a behavioral cognitive marker for differential Alzheimer's disease diagnosis. *Journal of Neuroscience, 32*(6), 1942–1952. doi:10.1523/JNEUROSCI.4556-11.2012

Belleville, S. (2008). Cognitive training for persons with mild cognitive impairment. *International Psychogeriatrics, 20*(1), 57–66. doi:10.1017/S104161020700631X

Belleville, S., Boller, B., & Prieto del Val, L. (2016). Cognitive Training in Mild Cognitive Impairment. In Cognitive Training (pp. 187-197). Springer International Publishing.

Belleville, S., Clément, F., Mellah, S., Gilbert, B., Fontaine, F., & Gauthier, S. (2011). Training-related brain plasticity in subjects at risk of developing Alzheimer's disease. *Brain, 134*(6), 1623–1634. doi:10.1093/brain/awr037

Belleville, S., Gilbert, B., Fontaine, F., Gagnon, L., Ménard, É., & Gauthier, S. (2006). Improvement of episodic memory in persons with mild cognitive impairment and healthy older adults: evidence from a cognitive intervention program. *Dementia and Geriatric Cognitive Disorders, 22*(5-6), 486–499. doi:10.1159/000096316

Belleville, S., Hudon, C., Bier, N., Brodeur, C., Gilbert, B., Grenier, S., . . . Gauthier, S. (2018). MEMO+: efficacy, durability and effect of cognitive training and psychosocial intervention in individuals with mild cognitive impairment. *Journal of the American Geriatrics Society*, 1–9. doi:10.1111/jgs.15192

Belleville, S., Sylvain-Roy, S., de Boysson, C., & Menard, M. C. (2008). Characterizing the memory changes in persons with mild cognitive impairment. In W. S. Sossin, J.-C. Lacaille, V. F. Castellucci, & S. Belleville (Eds.). *Progress in Brain Research* (vol.169, chapitre 23, 365–375): Elsevier B.V.

Bennett, I. J., Golob, E. J., Parker, E. S., & Starr, A. (2006). Memory evaluation in mild cognitive impairment using recall and recognition tests. *Journal of Clinical and Experimental Neuropsychology, 28*(8), 1408–1422. doi:10.1080/13803390500409583

Bherer, L., Kramer, A. F., Peterson, M. S., Colcombe, S., Erickson, K., & Becic, E. (2008). Transfer effects in task-set cost and dual-task cost after dual-task training in older and younger adults: Further evidence for cognitive plasticity in attentional control in late adulthood. *Experimental Aging Research, 34*(3), 188–219. doi:10.1080/03610730802070068

Bherer, L., Kramer, A. F., Peterson, M. S., Colcombe, S., Erickson, K., & Becic, E. (2005). Training effects on dual-task performance: Are there age-related differences in plasticity of attentional control?. *Psychology and Aging*, *20*(4), 695–709. doi:10.1037/0882-7974.20.4.695

Bier, B., de Boysson, C., & Belleville, S. (2014). Identifying training modalities to improve multitasking in older adults. *Age, 36*(4), 1–16. doi:10.1007/s11357-014-9688-2

Bier, B., Ouellet, É., & Belleville, S. (2018). Computerized attentional training and transfer with virtual reality: Effect of age and training type. *Neuropsychology*, *32*(5), 597–614. doi:10.1037/neu0000417

Biocca, F., & Delaney, B. (1995). Immersive virtual reality technology. In F. Biocca & M. R. Levy (Eds.), *Communication in the Age of Virtual Reality* (pp. 57–124). Hillsdale, NJ: Lawrence Elbaum Associates, Inc.

Bisson, E., Contant, B., Sveistrup, H., & Lajoie, Y. (2007). Functional balance and dual-task reaction times in older adults are improved by virtual reality and biofeedback training. *Cyberpsychology & Behavior, 10*(1), 16–23. doi:10.1089/cpb.2006.9997

Borella, E., Carretti, B., Mitolo, M., Zavagnin, M., Caffarra, P., Mammarella, N., . . . Piras, F. (2017). Characterizing cognitive inhibitory deficits in mild cognitive impairment. *Psychiatry Research*, *251*, 342–348. doi:10.1016/j.psychres.2016.12.037

Boucher, L. (2014). Contribution de la réalité virtuelle à l'identification d'un déficit cognitif léger chez les personnes âgées (Thèse de doctorat, Université du Québec à Trois-Rivières). Repéré à http://depot-e.uqtr.ca/7522/1/030826257.pdf

Bower, G. H. (1970). Analysis of a mnemonic device: Modern psychology uncovers the powerful components of an ancient system for improving memory. *American Scientist*, *58*(5), 496–510.

Brehmer, Y., Westerberg, H., & Bäckman, L. (2012). Working-memory training in younger and older adults: Training gains, transfer, and maintenance. *Frontiers in Human Neuroscience, 6*(63), 1–7. doi:10.3389/fnhum.2012.00063

Bruscoli, M., & Lovestone, S. (2004). Is MCI really just early dementia? A systematic review of conversion studies. *International Psychogeriatrics*, *16*(02), 129–140. doi:10.1017/S1041610204000092

Buschert, V. C., Friese, U., Teipel, S. J., Schneider, P., Merensky, W., Rujescu, D., . . . Buerger, K. (2011). Effects of a newly developed cognitive intervention in amnestic mild cognitive impairment and mild Alzheimer's disease: A pilot study. *Journal of Alzheimer's Disease, 25*(4), 679–694. doi:10.3233/JAD-2011-100999

Buschkuehl, M., Jaeggi, S. M., Hutchison, S., Perrig-Chiello, P., Däpp, C., Müller, M., . . . Perrig, W. J. (2008). Impact of working memory training on memory performance in old-old adults. *Psychology and Aging, 23*(4), 743–753. doi:10.1037/a0014342

Chaytor, N., & Schmitter-Edgecombe, M. (2003). The ecological validity of neuropsychological tests: A review of the literature on everyday cognitive skills. *Neuropsychology Review, 13*(4), 181–197. doi:10.1023/B:NERV.0000009483.91468.fb

Chen, Y., Denny, K. G., Harvey, D., Farias, S. T., Mungas, D., DeCarli, C., & Beckett, L. (2017). Progression from normal cognition to mild cognitive impairment in a diverse clinic-based and community-based elderly cohort. *Alzheimer's & Dementia*, *13*(4), 399–405. doi:10.1016/j.jalz.2016.07.151

Christensen, H. (1991). The validity of memory complaints by elderly persons. *International Journal of Geriatric Psychiatry*, *6*(5), 307–312. doi:10.1002/gps.930060507

Cipresso, P., Albani, G., Serino, S., Pedroli, E., Pallavicini, F., Mauro, A., & Riva, G. (2014). Virtual multiple errands test (VMET): A virtual reality-based tool to detect early executive functions deficit in Parkinson's disease. *Frontiers in Behavioral Neuroscience, 8*(405), 1–11. doi:10.3389/fnbeh.2014.00405

Clare, L., & Woods, R. T. (2004). Cognitive training and cognitive rehabilitation for people with early-stage Alzheimer's disease: A review. *Neuropsychological Rehabilitation*, *14*(4), 385–401. doi:10.1080/09602010443000074

Clément, F., Belleville, S., & Gauthier, S. (2008). Cognitive complaint in mild cognitive impairment and Alzheimer's disease. Journal of the International *Neuropsychological Society, 14*, 222–232. doi:10.10170S1355617708080260

Corriveau-Lecavalier, N., Ouellet, É., Boller, B., & Belleville, S. (2018). Use of immersive virtual reality to assess episodic memory: A validation study in older adults. *Neuropsychological Rehabilitation*, 1–19. doi:10.1080/09602011.2018.1477684

Coyle, H., Traynor, V., & Solowij, N. (2015). Computerized and virtual reality cognitive training for individuals at high risk of cognitive decline: Systematic review of the literature. *The American Journal of Geriatric Psychiatry,* 23(4), 335–359. doi:10.1016/j.jagp.2014.04.009

Craik, F. I. M., & Bialystok, E. (2006). Planning and task management in older adults: Cooking breakfast. *Memory and Cognition*, *34*(6), 1236–1249. doi:10.3758/BF03193268

Crumley, J. J., Stetler, C. A., & Horhota, M. (2014). Examining the relationship between subjective and objective memory performance in older adults: A meta-analysis. *Psychology and Aging, 29*(2), 250–263. doi:10.1037/a0035908

Cushman, L. A., Stein, K., & Duffy, C. J. (2008). Detecting navigational deficits in cognitive aging and Alzheimer disease using virtual reality. *Neurology, 71*(12), 888–895. doi:10.1212/01.wnl.0000326262.67613.fe

Czaja, S. J., Charness, N., Fisk, A. D., Hertzog, C., Nair, S. N., Rogers, W. A., & Sharit, J. (2006). Factors predicting the use of technology: Findings from the Center for Research and Education on Aging and Technology Enhancement (CREATE). *Psychology and Aging*, *21*(2), 333–352. doi:10.1037/0882-7974.21.2.333

Dahlin, E., Neely, A. S., Larsson, A., Bäckman, L., & Nyberg, L. (2008). Transfer of learning after updating training mediated by the striatum. *Science, 320*(5882), 1510–1512. doi:10.1126/science.1155466

Déjos, M., Sauzéon, H., & N'Kaoua, B. (2012). La réalité virtuelle au service de l'évaluation clinique de la personne âgée : le dépistage précoce de la démence. *Revue Neurologique*, *168*(5), 404–414. doi:10.1016/j.neurol.2011.09.005

Delis, D. C., Kramer, J. H., Kaplan, E., & Ober, B. A. (2000). *The California Verbal Learning Test–Second edition*, San Antonio, TX: The Psychological Corporation.

Derouesné, C., Lacomblez, L., Thibault, S., & Leponcin, M. (1999). Memory complaints in young and elderly subjects. *International Journal of Geriatric Psychiatry*, *14*(4), 291–301. doi:10.1002/(SICI)1099-1166(199904)14:4<291::AID GPS902>3.0.CO;2-7

Dik, M. G., Jonker, C., Comijs, H. C., Bouter, L. M., Twisk, J. W. R., Van Kamp, G. J., & Deeg, D. J. H. (2001). Memory complaints and APOE-ε4 accelerate cognitive decline in cognitively normal elderly. *Neurology*, *57*(12), 2217–2222. 10. 1212/ WNL. 57. 12. 2217

Drzezga, A., Grimmer, T., Peller, M., Wermke, M., Siebner, H., Rauschecker, J. P., . . . Kurz, A. (2005). Impaired Cross-Modal Inhibition in Alzheimer Disease. *PLoS Med, 2*(10), e288. doi:10.1371/journal.pmed.0020288

Dubois, B., Hampel, H., Feldman, H. H., Scheltens, P., Aisen, P., Andrieu, S., . . . Broich, K. (2016). Preclinical Alzheimer's disease: definition, natural history, and diagnostic criteria. *Alzheimer's & Dementia*, *12*(3), 292–323. doi:10.1016/j.jalz.2016.02.002

Dudas, R. B., Clague, F., Thompson, S. A., Graham, K. S., & Hodges, J. R. (2005). Episodic and semantic memory in mild cognitive impairment. *Neuropsychologia, 43*(9), 1266–1276. doi:10.1016/j.neuropsychologia.2004.12.005

Dufouil, C., Fuhrer, R., & Alpérovitch, A. (2005). Subjective cognitive complaints and cognitive decline: consequence or predictor? The epidemiology of vascular aging study. *Journal of the American Geriatrics Society*, *53*(4), 616–621. doi:10.1111/j.1532-5415.2005.53209.x

Edwards, J. D., Wadley, V. G., Myers, R. S., Roenker, D. L., Cissell, G. M., & Ball, K. K. (2002). Transfer of a speed of processing intervention to near and far cognitive functions. *Gerontology, 48*(5), 329–340. doi:10.1159/000065259

Edwards, J. D., Wadley, V. G., Vance, D. E., Wood, K., Roenker, D. L., & Ball, K. K. (2005). The impact of speed of processing training on cognitive and everyday performance. *Aging & Mental Health, 9*(3), 262–271. doi:10.1080/13607860412331336788

Elangovan, A. R., & Karakowsky, L. (1999). The role of trainee and environmental factors in transfer of training: An exploratory framework. *Leadership & Organization Development Journal, 20*(5), 268–276. doi:10.1108/01437739910287180

Engle, R. W. (2002). Working memory capacity as executive attention. *Current Directions in Psychological Science, 11*(1), 19–23. doi:10.1111/1467-8721.00160

Engvig, A., Fjell, A. M., Westlye, L. T., Moberget, T., Sundseth, Ø., Larsen, V. A., & Walhovd, K. B. (2010). Effects of memory training on cortical thickness in the elderly. *Neuroimage, 52*(4), 1667–1676. doi:10.1016/j.neuroimage.2010.05.041

Engvig, A., Fjell, A. M., Westlye, L. T., Skaane, N. V., Dale, A. M., Holland, D., . . . Walhovd, K. B. (2014). Effects of cognitive training on gray matter volumes in memory clinic patients with subjective memory impairment. *Journal of Alzheimer's Disease*, *41*(3), 779–791. doi:10.3233/JAD-131889

Engvig, A., Fjell, A. M., Westlye, L. T., Skaane, N. V., Sundseth, Ø., & Walhovd, K. B. (2012). Hippocampal subfield volumes correlate with memory training benefit in subjective memory impairment. *NeuroImage, 61*(1), 188–194. doi:10.1016/j.neuroimage.2012.02.072

Farrimond, S., Knight, R. G., & Titov, N. (2006). The effects of aging on remembering intentions: Performance on a simulated shopping task. *Applied Cognitive Psychology, 20*(4), 533–555. doi:10.1002/acp.1202

Findlater, L., Froehlich, J. E., Fattal, K., Wobbrock, J. O., & Dastyar, T. (2013, April). Age-related differences in performance with touchscreens compared to traditional mouse input. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 343–346). ACM.

Fort, I., Adoul, L., Holl, D., Kaddour, J., & Gana, K. (2004). Psychometric properties of the French version of the Multifactorial Memory Questionnaire for adults and the elderly. *Canadian Journal on Aging, 23*(4), 347–357. doi:10.1353/cja.2005.0020

Franzen, M. D., & Wilhelm, K. L. (1996). Conceptual foundations of ecological validity in neuropsychological assessment. In R. J. Sbordone & C. J. Long (Eds.), *Ecological validity of neuropsychological testing* (pp. 91–112). Boca Raton, FL: St. Lucie Press

Gadler, E., Grassi, A., & Riva, G. (2009). A rehabilitation protocol for empowering spatial orientation in MCI. A Pilot Study. *Annual Review of CyberTherapy and Telemedicine, 7*, 234–236. doi:10.3233/978-1-60750-017-9-234

Gagnon, L. G., & Belleville, S. (2012). Training of attentional control in mild cognitive impairment with executive deficits: Results from a double-blind randomised controlled study. *Neuropsychological Rehabilitation*, 1–27. doi:10.1080/09602011.2012.691044

Gagnon, M., Dartigues, J. F., Mazaux, J., Dequae, L., Letenneur, L., Giroire, J. M., & Barberger-Gateau, P. (1994). Self-reported memory complaints and memory performance in elderly French community residents: Results of the PAQUID Research Program. *Neuroepidemiology*, *13*(4), 145–154. doi:10.1159/000110373

Gamito, P., Oliveira, J., Coelho, C., Morais, D., Lopes, P., Pacheco, J., . . . Barata, A. F. (2017). Cognitive training on stroke patients via virtual reality-based serious games. *Disability and Rehabilitation*, *39*(4), 385–388. doi:10.3109/09638288.2014.934925

Gates, N. J., Sachdev, P. S., Singh, M. A. F., & Valenzuela, M. (2011). Cognitive and memory training in adults at risk of dementia: A systematic review. *BMC Geriatrics*, *11*(55), 1–14. doi:10.1186/1471-2318-11-55

Gauthier, S., Reisberg, B., Zaudig, M., Petersen, R. C., Ritchie, K., Broich, K., . . . Cummings, J. L. (2006). Mild cognitive impairment. *The Lancet*, *367*(9518), 1262–1270. doi:10.1016/S0140-6736(06)68542-5

Geerlings, M. I., Jonker, C., Bouter, L. M., Adèr, H. J., & Schmand, B. (1999). Association between memory complaints and incident Alzheimer's disease in elderly people with normal baseline cognition. *American Journal of Psychiatry*, *156*(4), 531–537.

Gilbert, B., Fontaine, S. F., Belleville, S., Gagnon, L., & Ménard, E. (2008). Programme d'intervention cognitive pour les aînés: programme MEMO, Montréal.

Glodzik-Sobanska, L., Reisberg, B., De Santi, S., Babb, J. S., Pirraglia, E., Rich, K. E., . . . de Leon, M. J. (2007). Subjective memory complaints: Presence, severity and future outcome in normal older subjects. *Dementia and Geriatric Cognitive Disorders*, *24*(3), 177–84. doi:10.1159/000105604

Gratzinger, P., Sheikh, J. I., Friedman, L., & Yesavage, J. A. (1990). Cognitive interventions to improve face-name recall: The role of personality trait differences. *Developmental Psychology*, *26*(6), 889–893. doi:10.1037/0012-1649.26.6.889

Gross, A. L., Brandt, J., Bandeen-Roche, K., Carlson, M. C., Stuart, E. A., Marsiske, M., & Rebok, G. W. (2014). Do older adults use the method of loci? Results from the ACTIVE study. *Experimental Aging Research, 40*(2), 140–163. doi:10.1080/0361073X.2014.882204

Gross, A. L., Parisi, J. M., Spira, A. P., Kueider, A. M., Ko, J. Y., Saczynski, J. S., . . . Rebok, G. W. (2012). Memory training interventions for older adults: A meta-analysis. *Aging & Mental Health, 16*(6), 722–734. doi:10.1080/13607863.2012.667783

Guerreiro, M. J., Murphy, D. R., & Van Gerven, P. W. (2010). The role of sensory modality in age-related distraction: A critical review and a renewed view. *Psychological Bulletin, 136*(6), 975–1022. doi:10.1037/a0020731

Hampstead, B. M., Stringer, A. Y., Stilla, R. F., Deshpande, G., Hu, X., Moore, A. B., & Sathian, K. (2011). Activation and effective connectivity changes following explicit-memory training for face–name pairs in patients with mild cognitive impairment: A pilot study. *Neurorehabilitation and Neural Repair*, *25*(3), 210–222. doi:10.1177/1545968310382424

Hampstead, B. M., Sathian, K., Moore, A. B., Nalisnick, C., & Stringer, A. Y. (2008). Explicit memory training leads to improved memory for face-name pairs in patients with mild cognitive impairment: Results of a pilot investigation. *Journal of the International Neuropsychological Society, 14*(5), 883–889. doi:10.10170S1355617708081009

Hampstead, B. M., Stringer, A. Y., Stilla, R. F., Giddens, M., & Sathian, K. (2012). Mnemonic strategy training partially restores hippocampal activity in patients with mild cognitive impairment. *Hippocampus, 22*(8), 1652–1658. doi:10.1002/hipo.22006

Head, D., & Isom, M. (2010). Age effects on wayfinding and route learning skills. *Behavioural Brain Research, 209*(1), 49–58. doi:10.1016/j.bbr.2010.01.012

Herrera, C., Chambon, C., Michel, B., Paban, V., & Alescio-Lautier, B. (2012). Positive effects of computer-based cognitive training in adults with mild cognitive impairment. *Neuropsychologia*, *50*, 1871–1881. doi:10.1016/j.neuropsychologia.2012.04.012

Herrmann, D. J. (1982). Know thy memory: The use of questionnaires to assess and study memory. *Psychological Bulletin*, *92*(2), 434–452. doi:10.1037/0033-2909.92.2.434

Hess, T. M., Popham, L. E., Emery, L., & Elliott, T. (2012). Mood, motivation, and misinformation: Aging and affective state influences on memory. *Aging, Neuropsychology, and Cognition, 19*(1-2), 13–34. doi:10.1080/13825585.2011.622740

Hill, R. D., Sheikh, J. I., & Yesavage, J. (1987). The effect of mnemonic training on perceived recall confidence in the elderly. *Experimental Aging Research, 13*(4), 185–188. doi:10.1080/03610738708259323

Hill, R. D., Yesavage, J. A., Sheikh, J., & Friedman, L. (1989). Mental status as a predictor of response to memory training in older adults. *Educational Gerontology: An International Quarterly*, *15*(6), 633–639.

Hofmann, M., Rösler, A., Schwarz, W., Müller-Spahn, F., Kräuchi, K., Hock, C., & Seifritz, E. (2003). Interactive computer-training as a therapeutic tool in Alzheimer's disease. *Comprehensive Psychiatry, 44*(3), 213–219. doi:10.1016/s0010-440x(03)00006-3

Hohman, T. J., Beason-Held, L. L., Lamar, M., & Resnick, S. M. (2011). Subjective cognitive complaints and longitudinal changes in memory and brain function. *Neuropsychology*, *25*(1), 125–130. doi:10.1037/a0020859

Hollman, J. H., Kovash, F. M., Kubik, J. J., & Linbo, R. A. (2007). Age-related differences in spatiotemporal markers of gait stability during dual task walking. *Gait & Posture, 26*(1), 113–119. doi:10.1016/j.gaitpost.2006.08.005

Hudon, C., Belleville, S., & Gauthier, S. (2009). The assessment of recognition memory using the Remember/Know procedure in amnestic mild cognitive impairment and probable Alzheimer's disease. *Brain and Cognition, 70*(1), 171–179. doi:10.1016/j.bandc.2009.01.009

Hudon, C., Belleville, S., Souchay, C., Gély-Nargeot, M.-C., Chertkow, H., & Gauthier, S. (2006). Memory for gist and detail information in Alzheimer's disease and mild cognitive impairment. *Neuropsychology, 20*(5), 566–577. doi:10.1037/0894-4105.20.5.566

Hudon, C., Villeneuve, S., & Belleville, S. (2011). The effect of semantic orientation at encoding on free-recall performance in amnestic mild cognitive impairment and probable Alzheimer's disease. *Journal of Clinical and Experimental Neuropsychology, 33*(6), 631–638. doi:10.1080/13803395.2010.547663

Ivanoiu, A., Adam, S., Van der Linden, M., Salmon, E., Juillerat, A. C., Mulligan, R., & Seron, X. (2005). Memory evaluation with a new cued recall test in patients with mild cognitive impairment and Alzheimer's disease. *Journal of Neurology*, *252*(1), 47–55. doi:10.1007/s00415-005-0597-2

Jaeger, B. K., & Mourant, R. R. (2001, October). Comparison of simulator sickness using static and dynamic walking simulators. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* (Vol. 45, No. 27, pp. 1896–1900). SAGE Publications. doi:10.1177/154193120104502709

Jean, L., Bergeron, M. È., Thivierge, S., & Simard, M. (2010). Cognitive intervention programs for individuals with mild cognitive impairment: Systematic review of the literature. *American Journal of Geriatric Psychiatry, 18*(4), 281–296. doi:10.1097/JGP.0b013e3181c37ce9

Jebara, N., Orriols, E., Zaoui, M., Berthoz, A., & Piolino, P. (2014). Effects of enactment in episodic memory: A pilot virtual reality study with young and elderly adults. *Frontiers in Aging Neuroscience, 6*, 1–16. doi:10.3389/fnagi.2014.00338

Jessen, F., Amariglio, R. E., Van Boxtel, M., Breteler, M., Ceccaldi, M., Chételat, G., . . . Glodzik, L. (2014). A conceptual framework for research on subjective cognitive decline in preclinical Alzheimer's disease. *Alzheimer's & dementia, 10*(6), 844–852. doi:10.1016/j.jalz.2014.01.001

Jessen, F., Wiese, B., Bachmann, C., Eifflaender-Gorfer, S., Haller, F., Kölsch, H., . . . Wagner, M. (2010). Prediction of dementia by subjective memory impairment: Effects of severity and temporal association with cognitive impairment. *Archives of general psychiatry, 67*(4), 414–422. doi:10.1001/archgenpsychiatry.2010.30.

Jobe, J. B., Smith, D. M., Ball, K., Tennstedt, S. L., Marsiske, M., Willis, S. L., . . . Kleinman, K. (2001). ACTIVE: A cognitive intervention trial to promote independence in older adults. *Controlled Clinical Trials, 22*(4), 453–479. doi:10.1016/S0197-2456(01)001398

Johns, E. K., Phillips, N. A., Belleville, S., Goupil, D., Babins, L., Kelner, N., . . . Duncan, H. D. (2012). The Profile of Executive Functioning in Amnestic Mild Cognitive Impairment: Disproportionate Deficits in Inhibitory Control. *Journal of the International Neuropsychological Society, 18*(03), 541–555. doi:10.1017/S1355617712000069

Jonker, C., Geerlings, M. I., & Schmand, B. (2000). Are memory complaints predictive for dementia? A review of clinical and population-based studies. *International Journal of Geriatric Psychiatry, 15*(11), 983–991. doi:10.1002/1099-1166(200011)15:11<983::AID-GPS238>3.0.CO;2-5

Jonker, C., Launer, L. J., Hooijer, C., & Lindeboom, J. (1996). Memory complaints and memory impairment in older individuals. *Journal of the American Geriatrics Society*, *44*(1), 44–49. doi:10.1111/j.1532-5415.1996.tb05636.x

Jorm, A. F., Christensen, H., Korten, A. E., Jacomb, P. A., & Henderson, A. S. (2001). Memory complaints as a precursor of memory impairment in older people: A longitudinal analysis over 7-8 years. *Psychological Medicine*, *31*(3), 441–449.

Kelly, M. E., Loughrey, D., Lawlor, B. A., Robertson, I. H., Walsh, C., & Brennan, S. (2014). The impact of cognitive training and mental stimulation on cognitive and everyday functioning of healthy older adults: A systematic review and meta-analysis. *Ageing Research Reviews*, *15*, 28–43. doi:10.1016/j.arr.2014.02.004

Kim, A., Darakjian, N., & Finley, J. M. (2017). Walking in fully immersive virtual environments: An evaluation of potential adverse effects in older adults and individuals with Parkinson's disease. *Journal of Neuroengineering and Rehabilitation, 14*(1), 16–27. doi:10.1186/s12984-017-0225-2

Kinsella, G. J., Mullaly, E., Rand, E., Ong, B., Burton, C., Price, S., . . . Storey, E. (2009). Early intervention for mild cognitive impairment: A randomised controlled trial. *Journal of Neurology, Neurosurgery & Psychiatry*, *80*(7), 730–736. doi:10.1136/jnnp.2008.148346

Kliegl, R., Smith, J., & Baltes, P. B. (1989). Testing-the-limits and the study of adult age differences in cognitive plasticity of a mnemonic skill. *Developmental Psychology*, *25*(2), 247–256. doi:10.1037/0012-1649.25.2.247

Kramer, A. F., Larish, J. F., & Strayer, D. L. (1995). Training for attentional control in dual task settings: A comparison of young and old adults. *Journal of Experimental Psychology: Applied*, *1*(1), 50–76. doi:10.1037/1076-898X.1.1.50

Kurz, A., Pohl, C., Ramsenthaler, M., & Sorg, C. (2009). Cognitive rehabilitation in patients with mild cognitive impairment. *International Journal of Geriatric Psychiatry, 24*(2), 163–168. doi:10.1136/jnnp.2008.148346

Lampit, A., Hallock, H., & Valenzuela, M. (2014). Computerized cognitive training in cognitively healthy older adults: A systematic review and meta-analysis of effect modifiers. *PLoS Med, 11*(11), e1001756. doi:10.1371/journal.pmed.1001756

Langlois, A.-S., & Belleville, S. (2014). Subjective cognitive complaint in healthy older adults: Identification of major domains and relation to objective performance. *Aging, Neuropsychology, and Cognition, 21*(3), 257–282. doi:10.1080/13825585.2013.795928

Li, S. C., Schmiedek, F., Huxhold, O., Röcke, C., Smith, J., & Lindenberger, U. (2008). Working memory plasticity in old age: Practice gain, transfer, and maintenance. *Psychology and Aging*, *23*(4), 731–742. doi:10.1037/a0014343

Lim, M. H., Liu, K. P., Cheung, G. S., Kuo, M. C., Li, R., & Tong, C.-Y. (2012). Effectiveness of a Multifaceted Cognitive Training Programme for People with Mild Cognitive Impairment: A One-Group Pre-and Posttest Design. *Hong Kong Journal of Occupational Therapy*, *22*(1), 3–8. doi:10.1016/j.hkjot.2012.04.002

Lussier, M., Gagnon, C., & Bherer, L. (2012). An investigation of response and stimulus modality transfer effects after dual-task training in younger and older. *Frontiers in Human Neuroscience, 6*(129), 1–11. doi:10.3389/fnhum.2012.00129

Lustig, C., & Flegal, K. E. (2008). Targeting latent function: Encouraging effective encoding for successful memory training and transfer. *Psychology and Aging, 23*(4), 754–764. doi:10.1037/a0014295

Lustig, C., Shah, P., Seidler, R., & Reuter-Lorenz, P. A. (2009). Aging, training, and the brain: A review and future direction. *Neuropsychology review, 19*, 504–522. doi:10.1007/s11065-009-9119-9

Man, D. W., Chung, J. C., & Lee, G. Y. (2012). Evaluation of a virtual reality-based memory training programme for Hong Kong Chinese older adults with questionable dementia: A pilot study. *International Journal of Geriatric Psychiatry, 27*(5), 513–520. doi:10.1177/1545968309353328

McDonald-Miszczak, L., Hertzog, C., & Hultsch, D. F. (1995). Stability and accuracy of metamemory in adulthood and aging: A longitudinal analysis. *Psychology and Aging*, *10*(4), 553–564. doi:10.1037/0882-7974.10.4.553

McGinnis, A. M. (2016). The Near and Far Transfer Effects of Multimedia Cognitive Training (Mémoire de maîtrise, Abilene Christian University). Repéré à http://digitalcommons.acu.edu/etd/11/

McKhann, G., Drachman, D., Folstein, M., Katzman, R., Price, D., & Stadlan, E. M. (1984). Clinical diagnosis of Alzheimer's disease. Report of the NINCDS-ADRDA work group under the auspices of the Department of Health and Human Services Task Force on Alzheimer's Disease. Neurology, *34(7)*. 939–944. doi:10.1212/WNL.34.7.939

McKhann, G. M., Knopman, D. S., Chertkow, H., Hyman, B. T., Jack, C. R., Kawas, C. H., . . . Mayeux, R. (2011). The diagnosis of dementia due to Alzheimer's disease: Recommendations from the National Institute on Aging-Alzheimer's Association workgroups on diagnostic guidelines for Alzheimer's disease. *Alzheimer's & Dementia, 7*(3), 263–269. doi:10.1016/j.jalz.2011.03.005.

Minett, T. S. C., Da Silva, R. V., Ortiz, K. Z., & Bertolucci, P. H. F. (2008). Subjective memory complaints in an elderly sample: A cross-sectional study. *International Journal of Geriatric Psychiatry, 23*(1), 49–54. doi:10.1097/00019442-200508000-00005

Minett, T. S. C., Dean, J. L., Firbank, M., English, P., & O'brien, J. T. (2005). Subjective memory complaints, white-matter lesions, depressive symptoms, and cognition in elderly patients. *The American Journal of Geriatric Psychiatry*, *13*(8), 665–671. doi:10.1097/00019442-200508000-00005

Minocha, S., Tudor, A. D., & Tilling, S. (2017, July). Affordances of mobile virtual reality and their role in learning and teaching. In *Proceedings of the 31st British Computer Society Human Computer Interaction Conference* (p. 44). BCS Learning & Development Ltd.

Mirelman, A., Rochester, L., Maidan, I., Del Din, S., Alcock, L., Nieuwhof, F., . . . Abbruzzese, G. (2016). Addition of a non-immersive virtual reality component to treadmill training to reduce fall risk in older adults (V-TIME): A randomised controlled trial. *The Lancet, 388*(10050), 1170–1182. doi:10.1016/S0140-6736(16)31325-3

Mirelman, A., Rochester, L., Reelick, M., Nieuwhof, F., Pelosin, E., Abbruzzese, G., . . . Hausdorff, J. M. (2013). V-TIME: A treadmill training program augmented by virtual reality to decrease fall risk in older adults: study design of a randomized controlled trial. *BMC Neurology, 13*(1), 15–26. doi:10.1186/1471-2377-13-15

Mitchell, A. J., Beaumont, H., Ferguson, D., Yadegarfar, M., & Stubbs, B. (2014). Risk of dementia and mild cognitive impairment in older people with subjective memory complaints: Meta-analysis. *Acta Psychiatrica Scandinavica, 130*(6), 439–451. doi:10.1111/acps.12336

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex “frontal lobe” tasks: A latent variable analysis. *Cognitive Psychology, 41*(1), 49–100. doi:10.1006/cogp.1999.0734

Moffat, S. D., Zonderman, A. B., & Resnick, S. M. (2001). Age differences in spatial memory in a virtual environment navigation task. *Neurobiology of Aging, 22*(5), 787–796. doi:10.1016/S0197-4580(01)00251-2

Moroni, C. & Bayard, S. (2009). Processus d’inhibition: quelle est leur valeur évolutive après 50 ans? *Psychologie & Neuropsychiatrie du vieillissement, 7*, 121–129. doi:10.1684/pnv.2009.0155

Mowszowski, L., Lampit, A., Walton, C. C., & Naismith, S. L. (2016). Strategy-based cognitive training for improving executive functions in older adults: A systematic review. *Neuropsychology Review, 26*(3), 252–270. doi:10.1007/s11065-016-9329-x

Mozolic, J. L., Long, A. B., Morgan, A. R., Rawley-Payne, M., & Laurienti, P. J. (2011). A cognitive training intervention improves modality-specific attention in a randomized controlled trial of healthy older adults. *Neurobiology of Aging, 32*(4), 655–668. doi:10.1016/j.neurobiolaging.2009.04.013

Neill, W. T., Valdes, L. A., & Terry, K. M. (1995). Selective attention and the inhibitory control of cognition. In F. N. Dempster, C. J. Brainerd, & C. J. Brainerd (Eds.), *Interference and inhibition in cognition* (pp. 207-261). San Diego, CA: Academic Press.

O'Connor, D. W., Pollitt, P. A., Roth, M., Brook, C. P. B., & Reiss, B. B. (1990). Memory complaints and impairment in normal, depressed, and demented elderly persons identified in a community survey. *Archives of General Psychiatry*, *47*(3), 224–227. doi:10.1001/archpsyc.1990.01810150024005

Olchik, M. R., Farina, J., Steibel, N., Teixeira, A. R., & Yassuda, M. S. (2013). Memory training (MT) in mild cognitive impairment (MCI) generates change in cognitive performance. *Archives of Gerontology and Geriatrics, 56*(3), 442–447. doi:10.1016/j.archger.2012.11.007

Optale, G., Capodieci, S., Pinelli, P., Zara, D., Gamberini, L., & Riva, G. (2001). Music-enhanced Immersive Virtual Reality in the Rehabilitation of Memoryrelated Cognitive Processes and Functional Abilities: A Case Report. *Presence: Teleoperators and Virtual Environments, 10*(4), 450–462. doi:10.1162/1054746011470217

Optale, G., Urgesi, C., Busato, V., Marin, S., Piron, L., Priftis, K., . . . Bordin, A. (2010). Controlling Memory Impairment in Elderly Adults Using Virtual Reality Memory Training: A Randomized Controlled Pilot Study. *Neurorehabilitation and Neural Repair, 24*(4), 348–357. doi:10.1177/1545968309353328

Organisation mondiale de la Santé. (2016). La démence : aide-mémoire N°362. Repéré le 15 mars 2017 à http://www.who.int/mediacentre/factsheets/fs362/fr/

Park, D. C., Lautenschlager, G., Hedden, T., Davidson, N. S., Smith, A. D., & Smith, P. K. (2002). Models of visuospatial and verbal memory across the adult life span. *Psychology and Aging, 17*(2), 299–320. doi:10.1037//0882-7974.17.2.299

Parsons, T. D., & Rizzo, A. A. (2008). Initial validation of a virtual environment for assessment of memory functioning: Virtual reality cognitive performance assessment test. *CyberPsychology & Behavior, 11*(1), 17–25. doi:10.1089/cpb.2007.9934

Perkins, D. N., & Salomon, G. (1992). Transfer of learning. *International Encyclopedia of Education, 2*, 6452–6457.

Perri, R., Carlesimo, G. A., Serra, L., Caltagirone, C., & The early diagnosis group of the italian interdisciplinary network on Alzheimer's disease. (2005). Characterization of memory profile in subjects with amnestic mild cognitive impairment. *Journal of Clinical and Experimental Neuropsychology, 27*(8), 1033–1055. doi:10.1080/13803390490919317

Peter, J., Scheef, L., Abdulkadir, A., Boecker, H., Heneka, M., Wagner, M., . . . Alzheimer's Disease Neuroimaging Initiative. (2014). Gray matter atrophy pattern in elderly with subjective memory impairment. *Alzheimer's & Dementia*, *10*(1), 99–108. doi:10.1016/j.jalz.2013.05.1764

Petersen, R. C. (2002). Mild cognitive impairment: Transition from aging to Alzheimer's disease. In K. Iqbal, S. S. Sisodia and B. Winblad (Eds.), *Alzheimer's disease: Advances in etiology, pathogenesis and therapeutics* (pp. 141–151). John Wiley & Sons Ltd. doi:10.1002/0470846453.ch14

Petersen, R. C., Doody, R., Kurz, A., Mohs, R. C., Morris, J. C., Rabins, P. V., . . . Winblad, B. (2001). Current concepts in mild cognitive impairment. *Archives of Neurology*, *58*(12), 1985–1992. doi:10.1001/archneur.58.12.1985

Petersen, R. C., Smith, G. E., Waring, S. C., Ivnik, R. J., Tangalos, E. G., & Kokmen, E. (1999). Mild cognitive impairment: Clinical characterization and outcome. *Archives of Neurology*, *56*(3), 303–308. doi:10.1001/archneur.56.3.303

Plancher, G., Gyselinck, V., Nicolas, S., & Piolino, P. (2010). Age effect on components of episodic memory and feature binding: A virtual reality study. *Neuropsychology, 24*(3), 379–390. doi:10.1037/a0018680

Plancher, G., Nicolas, S., & Piolino, P. (2008). Apport de la réalité virtuelle en neuropsychologie de la mémoire: étude dans le vieillissement. *Psychologie & NeuroPsychiatrie du vieillissement*, *6*(1), 7–22. doi:10.1684/pnv.2008.0119

Plancher, G., Tirard, A., Gyselinck, V., Nicolas, S., & Piolino, P. (2012). Using virtual reality to characterize episodic memory profiles in amnestic mild cognitive impairment and Alzheimer's disease: Influence of active and passive encoding. *Neuropsychologia, 50*(5), 592–602. doi:10.1016/j.neuropsychologia.2011.12.013

Potvin, M.-J., Rouleau, I., Audy, J., Charbonneau, S., & Giguère, J.-F. (2011). Ecological prospective memory assessment in patients with traumatic brain injury. *Brain Injury, 25*(2), 192–205. doi:10.3109/02699052.2010.541896

Prichep, L. S., John, E. R., Ferris, S. H., Rausch, L., Fang, Z., Cancro, R., . . . Reisberg, B. (2006). Prediction of longitudinal cognitive decline in normal elderly with subjective complaints using electrophysiological imaging. *Neurobiology of aging*, *27*(3), 471–481. doi:10.1016/j.neurobiolaging.2005.07.021

Radvansky, G. A., Zacks, R. T., & Hasher, L. (2005). Age and inhibition: The retrieval of situation models. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, *60*(5), 276–278. doi:10.1093/geronb/60.5.P276

Rand, D., Katz, N., & Weiss, P. L. (2007). Evaluation of virtual shopping in the VMall: Comparison of post-stroke participants to healthy control groups. *Disability and Rehabilitation*, *29*(22), 1710–1719. doi:10.1080/09638280601107450

Rebok, G. W., & Balcerak, L. J. (1989). Memory self-efficacy and performance differences in young and old adults: The effect of mnemonic training. *Developmental Psychology*, *25*(5), 714–721. doi:10.1037/0012-1649.25.5.714

Rebok, G. W., Ball, K., Guey, L. T., Jones, R. N., Kim, H. Y., King, J. W., . . . Willis, S. L. (2014). Ten-year effects of the ACTIVE cognitive training trial on cognition and everyday functioning in older adults. *Journal of the American Geriatrics Society*, *62*(1), 16–24. doi:10.1111/jgs.12607.

Rebok, G. W., Carlson, M. C., & Langbaum, J. B. (2007). Training and maintaining memory abilities in healthy older adults: traditional and novel approaches. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences, 62*(Special Issue 1), 53–61. doi:10.1093/geronb/62.special_issue1.53

Reisberg, B., & Gauthier, S. (2008). Current evidence for subjective cognitive impairment (SCI) as the pre-mild cognitive impairment (MCI) stage of subsequently manifest Alzheimer's disease. *International Psychogeriatrics*, *20*(1), 1–16. doi:10.1017/S1041610207006412

Reisberg, B., Shulman, M. B., Torossian, C., Leng, L., & Zhu, W. (2010). Outcome over seven years of healthy adults with and without subjective cognitive impairment. *Alzheimer's and Dementia, 6*(1), 11–24. doi:10.1016/j.jalz.2009.10.002

Richmond, L. L., Morrison, A. B., Chein, J. M., & Olson, I. R. (2011). Working memory training and transfer in older adults. *Psychology and Aging*, *26*(4), 813–822. doi:10.1037/a0023631

Rizzo, A. A., Schultheis, M., Kerns, K. A., & Mateer, C. (2004). Analysis of assets for virtual reality applications in neuropsychology. *Neuropsychological Rehabilitation, 14*(1-2), 207–239. doi:10.1080/09602010343000183

Rizzo, M., McGehee, D. V., Dawson, J. D., & Anderson, S. N. (2001). Simulated car crashes at intersections in drivers with Alzheimer disease. *Alzheimer Disease & Associated Disorders, 15*(1), 10–20. doi:10.1097/00002093-200101000-00002

Rizzo, M., Reinach, S., McGehee, D., & Dawson, J. (1997). Simulated car crashes and crash predictors in drivers with Alzheimer disease. *Archives of Neurology*, *54*(5), 545–551. doi:10.1001/archneur.1997.00550170027011

Robertson-Tchabo, E. A., Hausman, C. P., & Arenberg, D. (1976). A classical mnemonic for older learners: A trip that works! *Educational Gerontology: An International Quarterly*, *1*(3), 215–226. doi:10.1080/0360127760010301

Roenker, D. L., Cissell, G. M., Ball, K. K., Wadley, V. G., & Edwards, J. D. (2003). Speed-of-processing and driving simulator training result in improved driving performance. *Human factors, 45*(2), 218–233. doi:10.1518/hfes.45.2.218.27241

Rogers, W. A., Fisk, A. D., McLaughlin, A. C., & Pak, R. (2005). Touch a screen or turn a knob: Choosing the best device for the job. *Human Factors*, *47*(2), 271–288. doi:10.1518/0018720054679452

Rosen, A. C., Sugiura, L., Kramer, J. H., Whitfield-Gabrieli, S., & Gabrieli, J. D. (2011). Cognitive training changes hippocampal function in mild cognitive impairment: A pilot study. *Journal of Alzheimer's Disease, 26*, 349–357. doi:10.3233/JAD-2011-0009

Rozzini, L., Costardi, D., Chilovi, B. V., Franzoni, S., Trabucchi, M., & Padovani, A. (2007). Efficacy of cognitive rehabilitation in patients with mild cognitive impairment treated with cholinesterase inhibitors. *International Journal of Geriatric Psychiatry, 22*(4), 356–360. doi:10.1002/gps.1681

Saposnik, G., & Levin, M. (2011). Virtual reality in stroke rehabilitation a meta-analysis and implications for clinicians. *Stroke, 42*(5), 1380–1386. doi:10.1161/STROKEAHA.110.605451

Sauzéon, H., N'Kaoua, B., Arvind Pala, P., Taillade, M., & Guitton, P. (2016). Age and active navigation effects on episodic memory: A virtual reality study. *British Journal of Psychology*, *107*(1), 72–94. doi:10.1111/bjop.12123

Sauzéon, H., N'Kaoua, B., Pala, P. A., Taillade, M., Auriacombe, S., & Guitton, P. (2016). Everyday-like memory for objects in ageing and Alzheimer's disease assessed in a visually complex environment: The role of executive functioning and episodic memory. *Journal of Neuropsychology*, *10*, 33–58. doi:10.1111/jnp.12055

Sauzéon, H., Pala, P. A., Larrue, F., Wallet, G., Déjos, M., Zheng, X., . . . N'Kaoua, B. (2012). The use of virtual reality for episodic memory assessment. *Experimental Psychology*, *59*, 99–108. doi:10.1027/1618-3169/a000131

Schreiber, M. (1999). Potential of an interactive computer-based training in the rehabilitation of dementia: An Initial Study. *Neuropsychological Rehabilitation, 9*(2), 155–167. doi:10.1080/713755596

Scogin, F., Storandt, M., & Lott, L. (1985). Memory-skills training, memory complaints, and depression in older adults. *Journal of Gerontology, 40*(5), 562–568. doi:10.1093/geronj/40.5.562

Serra, L., Bozzali, M., Cercignani, M., Perri, R., Fadda, L., Caltagirone, C., & Carlesimo, G. A. (2010). Recollection and familiarity in amnesic mild cognitive impairment. *Neuropsychology*, *24*(3), 316–326. doi:10.1037/a0017654

Sharples, S., Cobb, S., Moody, A., & Wilson, J. R. (2008). Virtual reality induced symptoms and effects (VRISE): Comparison of head mounted display (HMD), desktop and projection display systems. *Displays*, *29*(2), 58–69. doi:10.1016/j.displa.2007.09.005

Simon, S. S., Yokomizo, J. E., & Bottino, C. M. (2012). Cognitive intervention in amnestic Mild Cognitive Impairment: A systematic review. *Neuroscience & Biobehavioral Reviews, 36*(4), 1163–1178. doi:10.1016/j.neubiorev.2012.01.007

Simons, D. J., Boot, W. R., Charness, N., Gathercole, S. E., Chabris, C. F., Hambrick, D. Z., & Stine-Morrow, E. A. (2016). Do "brain-training" programs work? *Psychological Science in the Public Interest*, *17*(3), 103–186. doi:10.1177/1529100616661983

Slater, M., & Wilbur, S. (1997). A framework for immersive virtual environments (FIVE): Speculations on the role of presence in virtual environments. *Presence: Teleoperators and Virtual Environments, 6*(6), 603–616. doi:10.1162/pres.1997.6.6.603

Smith, G. E., Housen, P., Yaffe, K., Ruff, R., Kennison, R. F., Mahncke, H. W., & Zelinski, E. M. (2009). A cognitive training program based on principles of brain plasticity: Results from the Improvement in Memory with Plasticity-based Adaptive Cognitive Training

(IMPACT) Study. *Journal of the American Geriatrics Society, 57*(4), 594–603. doi:10.1111/j.1532-5415.2008.02167.x

Smith, M. W., Sharit, J., & Czaja, S. J. (1999). Aging, motor control, and the performance of computer mouse tasks. *Human Factors*, *41*(3), 389–396. doi:10.1518/001872099779611102

Sperling, R. A., Aisen, P. S., Beckett, L. A., Bennett, D. A., Craft, S., Fagan, A. M., . . . Montine, T. J. (2011). Toward defining the preclinical stages of Alzheimer's disease: Recommendations from the National Institute on Aging-Alzheimer's Association workgroups on diagnostic guidelines for Alzheimer's disease. *Alzheimer's & Dementia, 7*(3), 280–292. doi:10.1016/j.jalz.2011.03.003

Spieker, E. A., Astur, R. S., West, J. T., Griego, J. A., & Rowland, L. M. (2012). Spatial memory deficits in a virtual reality eight-arm radial maze in schizophrenia. *Schizophrenia Research, 135*(1-3), 84–89. doi:10.1016/j.schres.2011.11.014

St John, P., & Montgomery, P. (2002). Are cognitively intact seniors with subjective memory loss more likely to develop dementia? *International Journal of Geriatric Psychiatry*, *17*(9), 814–820. doi:10.1002/gps.559

Statistique Canada. (2017). Chiffres selon l'âge et le sexe, et selon le type de logement : faits saillants du recensement de 2016. Repéré à http://www.statcan.gc.ca/daily-quotidien/170503/dq170503a-fra.htm

Stott, J., & Spector, A. (2011). A review of the effectiveness of memory interventions in mild cognitive impairment (MCI). *International Psychogeriatrics, 23*(4), 526–538. doi:10.1017/S1041610210001973

Sugano, K., Yokogawa, M., Yuki, S., Dohmoto, C., Yoshita, M., Hamaguchi, T., . . . Yamada, M. (2012). Effect of cognitive and aerobic training intervention on older adults with mild or no cognitive impairment: A derivative study of the nakajima project. *Dementia and Geriatric Cognitive Disorders Extra, 2*(1), 69–80. doi:10.1159/000337224

Talassi, E., Guerreschi, M., Feriani, M., Fedi, V., Bianchetti, A., & Trabucchi, M. (2007). Effectiveness of a cognitive rehabilitation program in mild dementia (MD) and mild cognitive impairment (MCI): A case control study. *Archives of Gerontology and Geriatrics, 44*, 391–399. doi:10.1016/j.archger.2007.01.055

Tannenbaum, C., Mayo, N., & Ducharme, F. (2005). Older women's health priorities and perceptions of care delivery: Results of the WOW health survey. *Canadian Medical Association Journal*, *173*(2), 153–159. doi:10.1503/cmaj.050059

Tappen, R. M., & Hain, D. (2014). The effect of in-home cognitive training on functional performance of individuals with mild cognitive impairment and early-stage Alzheimer's disease. *Research in Gerontological Nursing, 7*(1), 14–24. doi:10.3928/19404921-20131009-01

Tarnanas, I., Laskaris, N., Tsolaki, M., Muri, R., Nef, T., & Mosimann, U. P. (2015). On the comparison of a novel serious game and electroencephalography biomarkers for early dementia screening. In P. Vlamos and A. Alexiou (Eds.), *GeNeDis 2014. Advances in Experimental Medicine and Biology* (Vol. 821, pp. 63–77). Springer, Cham. doi:10.1007/978-3-319-08939-3_11

Tarnanas, I., Schlee, W., Tsolaki, M., Müri, R., Mosimann, U., & Nef, T. (2013). Ecological validity of virtual reality daily living activities screening for early dementia: longitudinal study. *JMIR Serious Games, 1*(1), e1. doi:10.2196/games.2778

Tepest, R., Wang, L., Csernansky, J. G., Neubert, P., Heun, R., Scheef, L., & Jessen, F. (2008). Hippocampal surface analysis in subjective memory impairment, mild cognitive impairment and Alzheimer's dementia. *Dementia and Geriatric Cognitive Disorders*, *26*(4), 323–329. doi:10.1159/000161057

Thorndike, E. L., & Woodworth, R. S. (1901). The influence of improvement in one mental function upon the efficiency of other functions. *Psychological Review, 8,* 247–261.

Tomycz, N. D., & Friedlander, R. M. (2011). Memory Training Unlocks Brain Plasticity in Prodromal Alzheimer's Disease. *Neurosurgery, 69*(2), N13-N14. doi:10.1227/01.neu.0000400013.85906.95

Traykov, L., Raoux, N., Latour, F., Gallo, L., Hanon, O., Baudic, S., . . . Rigaud, A. S. (2007). Executive Functions Deficit in Mild Cognitive Impairment. *Cognitive and Behavioral Neurology, 20*(4), 219–224. doi:10.1097/WNN.0b013e31815e6254

Troyer, A. K., Murphy, K. J., Anderson, N. D., Moscovitch, M., & Craik, F. I. (2008). Changing everyday memory behaviour in amnestic mild cognitive impairment: A randomised controlled trial. *Neuropsychological Rehabilitation, 18*(1), 65–88. doi:10.1080/09602010701409684

Tsai, A. Y. J., Yang, M. J., Lan, C. F., & Chen, C. S. (2008). Evaluation of effect of cognitive intervention programs for the community-dwelling elderly with subjective memory complaints. *International Journal of Geriatric Psychiatry, 23*(11), 1172–1174. doi:10.1002/gps.2050

Tulving, E. (1972). Episodic and semantic memory. In E. Tulving & W. Donaldson, (Eds.), *Organization of Memory* (pp. 382–403). New York, NY: Academic Press.

Vallejo, V., Wyss, P., Chesham, A., Mitache, A. V., Müri, R. M., Mosimann, U. P., & Nef, T. (2017). Evaluation of a new serious game based multitasking assessment tool for cognition and activities of daily living: Comparison with a real cooking task. *Computers in Human Behavior*, *70*, 500–506. doi:10.1016/j.chb.2017.01.021

Van der Linden, M., Coyette, F., Poitrenaud, J., Kalafat, M., Calacis, F., Wyns, C., . . . et les membres du GREMEM (2004). L'épreuve de rappel libre/rappel indicé à 16 items (RL/RI-16). In M. Van der Liden, S. Adam, A. Agniel, C. Baisset Mouly, et al. (Eds.), *L'évaluation des troubles de la mémoire : Présentation de quatre tests de mémoire épisodique (avec leur étalonnage).* Marseille, France : Solal.

van Harten, A. C., Visser, P. J., Pijnenburg, Y. A., Teunissen, C. E., Blankenstein, M. A., Scheltens, P., & van der Flier, W. M. (2013). Cerebrospinal fluid Aβ42 is the best predictor of clinical progression in patients with subjective complaints. *Alzheimer's & Dementia*, *9*(5), 481–487. doi:10.1016/j.jalz.2012.08.004

van Oijen, M., de Jong, F. J., Hofman, A., Koudstaal, P. J., & Breteler, M. M. (2007). Subjective memory complaints, education, and risk of Alzheimer's disease. *Alzheimer's & Dementia*, *3*(2), 92–97. doi:10.1016/j.jalz.2007.01.011

Vance, D., Dawson, J., Wadley, V., Edwards, J., Roenker, D., Rizzo, M., & Ball, K. (2007). The accelerate study: The longitudinal effect of speed of processing training on cognitive performance of older adults. *Rehabilitation Psychology, 52*(1), 89–96. doi:10.1037/0090-5550.52.1.89

Vaportzis, E., Giatsi Clausen, M., & Gow, A. J. (2017). Older adults perceptions of technology and barriers to interacting with tablet computers: A focus group study. *Frontiers in Psychology*, *8*(article 1687), 1–11. doi:10.3389/fpsyg.2017.01687

Verhaeghen, P. (2016). Memory Training and Mnemonics. In S. Krauss Whitbourne (Ed.). *The Encyclopedia of Adulthood and Aging* (pp. 892–894). John Wiley & Sons, Inc. doi:10.1002/9781118521373.wbeaa076

Verhaeghen, P., Marcoen, A., & Goossens, L. (1992). Improving memory performance in the aged through mnemonic training: A meta-analytic study. *Psychology and Aging, 7*(2), 242–251. doi:10.1037/0882-7974.7.2.242

Visser, P. J., Verhey, F., Knol, D. L., Scheltens, P., Wahlund, L. O., Freund-Levi, Y., . . . Bürger, K. (2009). Prevalence and prognostic value of CSF markers of Alzheimer's disease pathology in patients with subjective cognitive impairment or mild cognitive impairment in the DESCRIPA study: A prospective cohort study. *The Lancet Neurology*, *8*(7), 619–627. doi:10.1016/S1474-4422(09)70139-5

Voelcker-Rehage, C. (2008). Motor-skill learning in older adults—a review of studies on age-related differences. *European Review of Aging and Physical Activity*, 5(1), 5–16. doi:10.1007/s11556-008-0030-9

Wang, L., Van Belle, G., Crane, P. K., Kukull, W. A., Bowen, J. D., McCormick, W. C., & Larson, E. B. (2004). Subjective memory deterioration and future dementia in people aged 65 and older. *Journal of the American Geriatrics Society*, *52*(12), 2045–2051. doi:10.1111/j.1532-5415.2004.52568.x

Weaver Cargin, J., Collie, A., Masters, C., & Maruff, P. (2008). The nature of cognitive complaints in healthy older adults with and without objective memory decline. *Journal of Clinical and Experimental Neuropsychology*, *30*(2), 245–257. doi:10.1080/13803390701377829

Weniger, G., & Irle, E. (2008). Allocentric memory impaired and egocentric memory intact as assessed by virtual reality in recent-onset schizophrenia. *Schizophrenia Research, 101*(1-3), 201–209. doi:10.1016/j.schres.2008.01.011

Werner, P., Rabinowitz, S., Klinger, E., Korczyn, A. D., & Josman, N. (2009). Use of the Virtual Action Planning Supermarket for the diagnosis of mild cognitive impairment. *Dementia and Geriatric Cognitive Disorders, 27*(4), 301–309. doi:10.1159/000204915

Westerberg, C. E., Paller, K. A., Weintraub, S., Mesulam, M. M., Holdstock, J. S., Mayes, A. R., & Reber, P. J. (2006). When memory does not fail: Familiarity-based recognition in mild cognitive impairment and Alzheimer's disease. *Neuropsychology*, *20*(2), 193–205. doi:10.1037/0894-4105.20.2.193

Wilkinson, A. J., & Yang, L. (2012). Plasticity of inhibition in older adults: Retest practice and transfer effects. *Psychology and Aging, 27*(3), 606–615. doi:10.1037/a0025926

Wilkinson, A. J., & Yang, L. (2015). Long-term maintenance of inhibition training effects in older adults: 1-and 3-year follow-up. *Journals of Gerontology Series B: Psychological Sciences and Social Sciences, 71*(4), 622–629. doi:10.1093/geronb/gbu179

Willis, S. L. & Belleville, S. (2016). Cognitive training in later adulthood. In K. W. Shaie & S. L. Willis (Eds.), *Handbook of the Psychology of Aging* (8th edition, pp. 219–243). London, UK: Elsevier.

Willis, S. L., Cornelius, S. W., Blow, F. C., & Baltes, P. B. (1983). Training research in aging: Attentional processes. *Journal of Educational Psychology, 75*(2), 257–270. doi:10.1037/0022-0663.75.2.257

Willis, S. L., Tennstedt, S. L., Marsiske, M., Ball, K., Elias, J., Koepke, K. M., . . . Wright, E. (2006). Long-term effects of cognitive training on everyday functional outcomes in older adults. *The Journal of the American Medical Association, 296*(23), 2805-2814. doi:10.1001/jama.296.23.2805

Witmer, B. G., & Singer, M. J. (1998). Measuring presence in virtual environments: A presence questionnaire. *Presence: Teleoperators and virtual environments, 7*(3), 225–240. doi:10.1162/105474698565686

Wolk, D. A., Signoff, E. D., & DeKosky, S. T. (2008). Recollection and familiarity in amnestic mild cognitive impairment: A global decline in recognition memory. *Neuropsychologia, 46*(7), 1965–1978. doi:10.1016/j.neuropsychologia.2008.01.017

Woltz, D. J., Gardner, M. K., & Gyll, S. P. (2000). The role of attention processes in near transfer of cognitive skills. *Learning and Individual Differences*, *12*(3), 209–251. doi:10.1016/S1041-6080(01)00038-3

Woollacott, M., & Shumway-Cook, A. (2002). Attention and the control of posture and gait: A review of an emerging area of research. *Gait & Posture, 16*(1), 1–14. doi:10.1016/S0966-6362(01)00156-4

World Alzheimer Report 2012, A public health priority. (2012). Organisation mondiale de la santé (OMS).

Yamnill, S., & McLean, G. N. (2001). Theories supporting transfer of training. *Human Resource Development Quarterly*, *12*(2), 195–208. doi:10.1002/hrdq.7

Yesavage, J. A. (1983). Imagery pretraining and memory training in the elderly. *Gerontology, 29*(4), 271–275. doi:10.1159/000213126

Yesavage, J. A. (1984). Relaxation and memory training in 39 elderly patients. *The American Journal of Psychiatry, 141*(6). 778–781.

Yesavage, J. A., & Rose, T. L. (1983). Concentration and mnemonic training in elderly subjects with memory complaints: A study of combined therapy and order effects. *Psychiatry Research*, *9*(2), 157–167. doi:10.1016/0165-1781(83)90037-9

Yesavage, J. A., & Rose, T. L. (1984a). The effects of a face-name mnemonic in young, middle-aged, and elderly adults. *Experimental Aging Research*, *10*(1), 55–57. doi:10.1080/03610738408258543

Yesavage, J. A., & Rose, T. L. (1984b). Semantic elaboration and the method of loci: A new trip for older learners. *Experimental Aging Research, 10(*3), 155–159. doi:10.1080/03610738408258560

Yesavage, J. A., Rose, T. L., & Bower, G. H. (1983). Interactive imagery and affective judgments improve face-name learning in the elderly. *Journal of Gerontology, 38*(2), 197–203. doi:10.1093/geronj/38.2.197

Yesavage, J. A., Sheikh, J. I., Friedman, L., & Tanke, E. (1990). Learning mnemonics: Roles of aging and subtle cognitive impairment. *Psychology and Aging*, *5*(1), 133–137. doi:10.1037//0882-7974.5.1.133

Yesavage, J. A., Sheikh, J. I, Tanke, E. D., & Hill, R. (1988). Response to memory training and individual differences in verbal intelligence and state anxiety. *American Journal of Psychiatry, 1*(45), 636–639. doi:10.1080/0380127890150607

York, L. (2003). Beyond the classroom: Transfer from work-based learning initiatives. In E. F. Holton & T. T. Baldwin (Eds.), *Managers as transfer agents: Improving learning transfer in organizations* (pp. 138–160). San Francisco, CA: Jossey Bass.

Zygouris, S., Giakoumis, D., Votis, K., Doumpoulakis, S., Ntovas, K., Sofia, S., . . . Tsolaki, M. (2014). Can a Virtual Reality Cognitive Training Application Fulfill a Dual Role? Using the Virtual Supermarket Cognitive Training Application as a Screening Tool for Mild Cognitive Impairment. *Journal of Alzheimer's Disease, 40*, 1–10.

doi:10.3233/JAD-14126

Annexe I : Chapitre de livre

Détection précoce de la maladie d'Alzheimer : les outils neuropsychologiques et leurs perspectives

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La maladie d'Alzheimer (MA) est une maladie neurodégénérative qui touche un grand nombre de personnes âgées et dont le coût social et économique est considérable. Le diagnostic avéré de la MA est posé quand l'examen histopathologique post-mortem révèle la présence de dégénérescences neurofibrillaires intracellulaires et de dépôts extracellulaires de protéine béta-amyloïde dans le cerveau d'un patient ayant présenté de son vivant tous les signes cliniques de la MA (McKhann et al.,1984 ; 2011). Du vivant du sujet, le diagnostic de la MA repose donc encore sur l'observation d'un ensemble de symptômes cognitifs qui ne peuvent être expliqués par d'autres causes biologiques ou psychologiques. Dans ce contexte, l'examen neuropsychologique joue un rôle tout à fait unique dans le diagnostic précoce et le diagnostic différentiel de la MA. L'examen neuropsychologique est particulièrement important dans les phases précoces de la maladie, car les mesures cognitives généralement utilisées lors de cet examen permettent de confirmer la présence d'une atteinte cognitive et d'en qualifier la nature. Dans ce chapitre, nous présenterons d'abord des travaux qui caractérisent l'atteinte neuropsychologique dans les stades très légers de la MA et qui cherchent à identifier des marqueurs cognitifs précoces. La seconde partie de ce chapitre présentera des études mettant en lien les atteintes cognitives précoces et les changements neuronaux mis en évidence par les techniques de neuroimagerie fonctionnelle. Enfin la troisième partie de ce chapitre expliquera de quelle façon la neuropsychologie peut contribuer à mieux comprendre les phénomènes de compensation cognitive et de plasticité cérébrale qui sont présents dans les phases précoces de la MA.

1. Évaluer le trouble cognitif léger pour identifier des marqueurs cognitifs précoces de la maladie d'Alzheimer

Il est maintenant reconnu que l'histoire naturelle de la MA comprend une longue période pendant laquelle on observe un déclin cognitif plus important que celui observé dans le vieillissement normal, mais insuffisant pour rencontrer les critères de la MA. Le déclin des fonctions cognitives observé dans la MA paraît débuter plusieurs années avant que les individus ne soient diagnostiqués avec la maladie (Amieva et al., 2008). Petersen (2003) a proposé un ensemble de critères permettant d'identifier ces personnes avec un *trouble cognitif léger* (TCL ou *mild cognitive impairment*) : plaintes mnésiques confirmées par l'entourage, déclin mnésique objectif (tenant compte de l'âge et du niveau de scolarité), fonctionnement cognitif global normal (tel que mesuré par des tests standardisés comme le MMSE ou le MoCA), autonomie préservée dans la vie quotidienne, et absence de diagnostic de démence. Plusieurs études ont montré que les personnes répondant à ces critères de TCL progressaient jusqu'à 10 fois plus souvent vers la MA que celles n'y répondant pas. L'étude des symptômes cognitifs et des changements cérébraux chez les personnes répondant aux critères de TCL pourrait donc contribuer à l'identification de marqueurs cognitifs sensibles et précoces de la MA.

Les études transversales sur le sujet ont montré que plusieurs des domaines cognitifs atteints dans la MA étaient aussi atteints dans le TCL. Par exemple, des déficits en mémoire épisodique et en mémoire travail sont observés dans le TCL, soit deux fonctions mnésiques altérées dans la MA. Par contre, pour une même fonction mnésique, il arrive que l'atteinte soit globale dans la MA, mais partielle dans le TCL. Des études ont aussi observé que pour les déficits communs, le niveau de performance mnésique des personnes avec TCL est le plus souvent intermédiaire entre celui des personnes saines et celui des personnes avec MA. Par exemple, en mémoire épisodique – qui permet d'encoder et de récupérer de l'information possédant un contexte spatio-temporel – les déficits observés dans la MA sont plus sévères que ceux observés dans le TCL, bien que les processus atteints soient les mêmes (voir Belleville, Sylvain-Roy, de Boysson, & Ménard, 2008 pour une revue).

Bien que l'on assume que les déficits des TCL progressent peu à peu jusqu'au diagnostic de la MA, ce ne sont pas toutes les personnes répondant aux critères du TCL qui évolueront vers une démence ou vers une MA. Une proportion non-négligeable de ces personnes ne développera jamais la maladie et certaines pourraient même revenir à un niveau de performance normal. Selon certaines études, 44% des patients identifiés avec un TCL ne répondraient plus aux critères un an plus tard (Ritchie, 2004 ; Ganguli, Shen, & DeKosky, 2004).

Plusieurs groupes de recherche tentent de déterminer lesquelles parmi les tâches atteintes chez les individus avec TCL permettent de distinguer ceux qui évolueront vers une MA (ou autre démence) de ceux qui demeureront stables. Autrement dit, des marqueurs cognitifs de progression du TCL vers la MA sont recherchés. Il faut alors déterminer si les tâches cognitives atteintes le sont davantage chez les TCL qui progressent que chez ceux qui ne progressent pas. Surtout, il importe de trouver des marqueurs ayant une bonne *sensibilité*, c'est-à-dire une capacité à révéler une atteinte chez les personnes qui évolueront vers la maladie, ainsi qu'une bonne *spécificité*, soit le fait qu'ils soient intacts chez les personnes qui demeureront stables. Les notions de sensibilité et de spécificité sont d'une importance déterminante pour le clinicien, car elles permettent de déterminer l'utilité des marqueurs à un niveau individuel.

Plusieurs études ont montré que les tests neuropsychologiques étaient davantage altérés chez les TLC qui progresseront vers la maladie que chez ceux qui demeureront stables (Bondi et al., 1994 ; Devanand, 2007 ; Landau et al., 2010) et que ceux-ci pouvaient représenter des marqueurs sensibles et spécifiques.

Dans le domaine de la mémoire épisodique, Villeneuve et Belleville (2012) ont tenté d'identifier certains marqueurs de détection précoce de la MA chez des personnes avec TCL, en s'intéressant à différentes composantes mnésiques qu'elles ont comparées à des biomarqueurs structurels, c'est-à-dire à certaines caractéristiques anatomiques du cerveau. Sur le plan de la mémoire épisodique, les chercheures ont évalué la performance de mémoire, la mémoire associative et la résistance à l'interférence proactive en utilisant des mots présentés en paires reliées ou non-reliées sémantiquement (p.ex. GIRAFE-CHÂTEAU ou FROMAGE-LAIT). Après quelques essais d'apprentissage, elles ont évalué la performance de mémoire en présentant des paires formées d'un seul des deux mots appris dans les paires préalables et d'un nouveau mot relié ou non relié (p.ex. GIRAFE-BALAI). La mémoire associative est celle qui permet de faire des liens entre deux stimuli reliés par leur contexte d'apprentissage. Par exemple, c'est elle qui permet d'associer en mémoire deux mots non-reliés sémantiquement comme GIRAFE-CHÂTEAU. L'interférence proactive réfère à l'effet confondant que produit l'apprentissage d'un événement sur l'apprentissage d'un événement ultérieur. Ainsi, le fait d'avoir mémorisé la paire GIRAFE-CHÂTEAU rend plus difficile l'apprentissage ultérieur de la paire GIRAFE-BALAI. Sur le plan des biomarqueurs structurels, l'étude utilisait l'imagerie par résonance magnétique pour mesurer le volume hippocampique ainsi que les anomalies de la substance blanche. Les chercheures ont établi que le volume de l'hippocampe était positivement corrélé avec la performance de mémoire associative, alors que les anomalies de la substance blanche se montraient positivement corrélées avec l'effet d'interférence en mémoire. Cela indique que les atteintes sur le plan de la mémoire associative et de la résistance à l'interférence chez les personnes avec TCL reflètent différents changements neuronaux. Par ailleurs, les chercheures ont montré avec une régression logistique (qui incluait les deux mesures de mémoire et les deux mesures structurelles) que seule la mesure de mémoire associative prédisait la progression ultérieure vers une démence.

Des études se sont aussi intéressées à d'autres types de mémoire comme marqueurs potentiels de progression vers une démence. Ainsi, Belleville, Chertkow et Gauthier (2007) ont étudié la mémoire de travail (MdeT) – qui permet le maintien et la manipulation d'information pour un court laps de temps et qui met en jeu différents processus de contrôle attentionnel. Notamment, l'attention divisée était mesurée en faisant appel à la procédure de Brown-Peterson, dans laquelle le participant doit diviser son attention entre une tâche de mémorisation d'un trigramme de consonnes et une tâche d'addition simple dont le délai varie selon les essais. Les capacités de manipulation ont été testées par la tâche d'empan alphabétique, en comparant un rappel immédiat d'une série de mots avec un rappel en ordre alphabétique. Les résultats indiquaient que les composantes de la MdeT sont sévèrement atteintes dans la MA. Dans le TCL, bien que l'attention divisée soit très altérée, la manipulation est intacte. Les deux composantes sont toutefois atteintes pour les personnes avec TCL qui progresseront ultérieurement vers la MA. De plus, il y a un continuum d'atteinte, les personnes avec MA montrant des performances inférieures à celles avec TCL, dont les performances sont inférieures aux personnes âgées saines. De plus, les individus avec TCL qui progressent ultérieurement vers la MA montrent des performances plus faibles que les TCL stables, et ce dans les deux tâches. Enfin, la performance aux tâches de contrôle attentionnel était corrélée avec la sévérité de la maladie. Ces résultats suggèrent que les déficits de contrôle attentionnel en MdeT caractérisent la MA dans les périodes précoces et qu'ils augmentent graduellement dans cette phase préclinique.

Dans une étude longitudinale prospective, Belleville et collaborateurs (en préparation) ont recruté plus d'une centaine de personnes avec TCL. Lors du recrutement, les participants complétaient un ensemble de tests pour mesurer leur mémoire épisodique, [mémoire de texte immédiat et différé, mémoire de listes de mots libre et indicé], le contrôle attentionnel en

MdeT [empan alphabétique, Brown Peterson, test d'alternance], la perception et le langage [Borb cercle, Borb orientation de ligne, Borb décision d'objets, dénomination DO-80]. Les participants étaient ensuite suivis pendant 12 à 60 mois. Pendant cette période, environ 35% des participants sont demeurés stables, alors que 65 % ont progressé vers une démence (MA ou autre). La comparaison des deux sous-groupes (TCL stables vs progresseurs) montrait des différences significatives sur un grand nombre de tâches, incluant des tâches de mémoire épisodique, des tâches de MdeT et des tâches de perception visuelle. Une analyse par régression logistique des données de cette étude indiquait que la combinaison des performances à un sous-ensemble des tâches de mémoire épisodique, de perception visuelle et de MdeT pouvait classifier correctement le pronostic futur (stable vs progresseur) de plus de 85% des participants. De plus, le modèle obtenu sur la base des tâches cognitives montrait une excellente sensibilité et spécificité (supérieure à 85% dans les deux cas). Ces résultats indiquent que quelques tests cognitifs suffisent à prédire si une personne avec TCL évoluera ou non vers une démence, et que l'algorithme optimal ne comprend pas que des tests de mémoire épisodique mais également, des tests de MdeT et de perception visuelle.

En résumé, des études identifient plusieurs tests neuropsychologiques sensibles aux premiers signes de la MA, voire même aux symptômes qui précèdent de plusieurs années l'établissement du diagnostic. Ces études montrent aussi que ces tests ont une bonne valeur prédictive et qu'un sous-ensemble peut être utile pour déterminer, parmi les personnes répondant aux critères du TCL, celles qui évolueront vers une démence. Globalement, il est suggéré que l'atteinte de la mémoire épisodique (dont la mémoire associative), des fonctions de contrôle attentionnel de la MdeT et possiblement de la perception, pris seuls ou en conjonction, seraient des marqueurs neuropsychologiques potentiels importants des phases précoces de la MA. Ces données illustrent la portée et l'intérêt de l'évaluation neuropsychologique pour le diagnostic précoce de la MA, surtout en l'absence de marqueurs biologiques sûrs.

2. La contribution de la neuroimagerie fonctionnelle dans la compréhension des atteintes cognitives associées aux phases précoces de la MA

Dans le domaine de la MA, les études de neuroimagerie structurelle permettent de déterminer les différences anatomiques retrouvées entre les cerveaux normaux et ceux des personnes atteintes de la maladie. Ces études ont porté sur les mesures d'épaisseur corticale et les mesures de volumétrie régionale (le volume de certaines régions connues pour être atteintes dans la MA comme l'hippocampe ou ses sous-régions spécifiques) en utilisant l'imagerie par résonance magnétique, ou sur les mesures des dépôts amyloïdes en utilisant l'imagerie de tomographie par émission de positons. Par contre, ces marqueurs biologiques restent des indicateurs imparfaits des signes cliniques ou du pronostic, autant au niveau de leur sensibilité que de leur spécificité (Katzman et al., 1988 ; Devanand, 2007 ; Fleisher et al., 2008). La neuroimagerie fonctionnelle, quant à elle, permet d'observer l'activité du cerveau lors de la réalisation de tâches cognitives. Elle permet d'identifier les régions qui sont responsables des atteintes cognitives et de mieux comprendre les processus – comme la plasticité, la réserve cognitive et/ou la compensation – qui agissent comme médiateurs entre les changements structuraux et leurs effets sur la cognition.

Les études en neuroimagerie fonctionnelle ayant porté sur des patients avec une MA avérée rapportent surtout des baisses d'activation dans plusieurs régions cérébrales, et ce surtout dans les régions qui semblent plus atteintes structurellement ou celles qui y sont connectées (Devous, 2002 ; Schwindt & Black, 2009 ; Villain, 2010). Ainsi, des baisses d'activation sont rapportées dans les régions temporales médianes, préfrontales, pariétales et cingulaires. En revanche, les personnes avec TCL montrent parfois des hyperactivations « paradoxales », c'est-à-dire que les activations observées dans certaines régions de leur cerveau sont plus importantes que celles observées chez les individus sains (Dickerson et al., 2004 ; Celone et al., 2006 ; Clément & Belleville, 2010 ; Clément, Belleville, & Mellah, 2010 ; Clément & Belleville, 2012). Des auteurs (Prvulovic et al., 2005 ; Celone et al., 2006 ; Sperling, 2007 ; Clément & Belleville, 2010 ; 2012) suggèrent que ces hyperactivations se mettent en place lors des phases les plus précoces du TCL, afin de compenser les déficits naissants. Au fur et à mesure de l'augmentation des atteintes structurelles et de la progression du TCL, le système ne serait plus en mesure de compenser les déficits, ce qui se manifesterait par une disparition des phénomènes d'hyperactivation en faveur de l'hypoactivation (Clément & Belleville, 2010). Ces phénomènes dynamiques accompagneraient le passage du TCL à la MA. Ces phénomènes ont été observés chez les individus avec TCL dans des tâches d'encodage en mémoire épisodique (Clément & Belleville, 2010), dans des tâches récupération en mémoire épisodique (Clément & Belleville, 2012), ainsi que dans des tâches qui mesurent des processus de contrôle attentionnel en MdeT (comme la manipulation ou l'attention divisée) (Clément, Gauthier, & Belleville, en révision). Autrement dit, il s'agit d'un phénomène relativement solide ne se limitant pas aux processus sous-tendus par les régions temporales médianes, typiquement dysfonctionnelles chez les TCL.

En somme, le TCL ne serait pas une condition homogène, ni sur le plan de la cognition, ni sur le plan cérébral. Certaines personnes atteintes de TCL montrent peu de déficits cognitifs et des hyperactivations cérébrales : elles se trouvent le plus souvent dans la *phase précoce* du TCL. D'autres individus avec un TCL montrent plutôt des déficits cognitifs plus marqués et des hypoactivations cérébrales : ils se trouvent le plus souvent dans la *phase tardive* du TCL, alors que la progression vers la MA est imminente.

3. Agir sur la plasticité cérébrale des personnes atteintes de TCL

Les études rapportées dans la section précédente mettent en évidence des phénomènes dynamiques de compensation cérébrale qui pourraient avoir des conséquences importantes pour la prise en charge des TCL. En effet, dans l'optique où les phénomènes d'hyperactivation retrouvés en TCL précoce sont compensatoires, ceux-ci devraient pouvoir être favorisés, voire amplifiés par des stratégies externes ciblées. On sait en effet que les activités cognitives stimulantes favorisent le bon fonctionnement cognitif et réduisent les risques de démence (Fratiglioni, Paillard-Borg, & Winblad, 2004 ; Wilson et al., 2002). Dans la même optique, les modèles de la réserve cognitive proposent que les individus diffèrent dans leur capacité à résister à des lésions cérébrales et cette différence proviendrait d'une variabilité dans les capacités de réserve cognitive. Selon ce modèle, un style de vie actif sur le plan cognitif augmente la capacité de réserve en favorisant la mise en place et l'accès à des réseaux cérébraux alternatifs et efficaces qui soutiennent la réorganisation cérébrale suite à un dommage au cerveau (Stern, 2002 ; Stern et al., 2005 ; Bier & Belleville, 2010 ; Villeneuve &

Belleville, 2010). Si la réalisation d'activités intellectuellement stimulantes au cours de la vie permet d'augmenter la capacité de réserve, il est possible de croire que la stimulation cognitive tardive puisse aussi favoriser le bon fonctionnement cognitif et minimiser la progression des symptômes chez les personnes avec TCL.

Belleville et ses collaborateurs (2006) ont mis en place un programme de recherche dans ce domaine en développant un programme d'entraînement cognitif adapté aux atteintes et aux forces cognitives qui caractérisent les personnes âgées saines et celles avec TCL (*MÉMO : Méthode d'Entraînement pour une Mémoire Optimale,* Gilbert, Fontaine, & Belleville, 2007). Ce programme propose un enseignement standardisé de stratégies de mémoire, qui font appel à l'imagerie visuelle (imagerie interactive, méthode des lieux, association nom-visage) et à l'élaboration sémantique (hiérarchisation de textes, organisation sémantique). Sur le plan pédagogique, le programme est élaboré de façon à promouvoir l'augmentation du sentiment d'auto-efficacité (modeling, support du groupe) ainsi que la généralisation (feedback fréquent, pratique individuelle et en groupe, exercices à la maison). Le programme comprend six à huit séances d'une à deux heures, offertes à des petits groupes de quatre ou cinq personnes. Une première étude réalisée auprès de personnes âgées saines et avec TCL a permis de montrer que suite au programme d'entraînement, les performances de mémoire des participants (mesurées en laboratoire et dans la vie quotidienne) étaient améliorées, autant chez les âgés sains que chez ceux avec TCL (taille d'effet modérée à large : 0,6 à 0,7 ; Belleville et al., 2006). Ces résultats suggèrent qu'un entraînement cognitif permet de compenser les déficits de mémoire épisodique chez les personnes atteintes d'un TCL. Une seconde étude (Belleville et al., 2011) a permis de déterminer les substrats neuronaux associés à cette intervention, en mesurant l'activité cérébrale de personnes âgées saines et avec TCL soumises au programme d'entraînement MÉMO. L'étude comportait trois mesures de l'activité cérébrale des participants via l'imagerie par résonance magnétique fonctionnelle lors de la réalisation d'une tâche de mémoire : une mesure six semaines avant l'entraînement, une seconde juste avant l'entraînement et une dernière après l'entraînement. L'étude cherchait à savoir quelles régions modifieraient leur activité suite à l'entraînement et si ces changements seraient observés dans des régions atteintes ou dans des régions intactes fonctionnellement. Suite au programme d'entraînement cognitif, des augmentations d'activation étaient observées lors de l'encodage et la récupération de mots en mémoire. Ces augmentations d'activation étaient notées dans plusieurs régions cérébrales dont les régions frontales, pariétales, temporales et au niveau des noyaux gris centraux. Certaines des régions dont l'activation était augmentée par l'intervention étaient déjà actives avant l'entraînement. Toutefois, plusieurs régions n'étaient pas sollicitées par la tâche de mémoire verbale avant l'intervention (par exemple, les noyaux gris centraux ou le lobule pariétal inférieur droit), ce qui suggère que l'intervention amenait les participants à utiliser un réseau de mémoire alternatif. Par ailleurs, toutes les régions sauf une (le lobule pariétal droit) étaient fonctionnellement intactes chez les TCL lors de la mesure précédant l'entraînement, donc similaires à celles des individus sains. Les auteurs concluent que l'entraînement a amené les participants TCL à recruter un réseau « intact » pour pallier leur trouble de mémoire. Par ailleurs, l'activité du lobule pariétal inférieur droit était corrélée positivement à la performance de mémoire. Ce lien supporte l'hypothèse voulant que ces changements d'activation aient un rôle compensatoire, et qu'ils permettent de minimiser les déficits de l'individu avec TCL. Les résultats portent à croire que cette compensation serait sous-tendue par des régions encore intactes : des réseaux alternatifs prendraient en charge les fonctions des régions atteintes.

Hampstead et ses collaborateurs (2010) ont aussi observé des augmentations d'activation chez des personnes avec TCL, en particulier dans les régions frontales médianes, pariétales et occipitales, suite à une intervention visant l'apprentissage d'associations de noms et de visages. Dans une autre étude, Hampstead et ses collaborateurs (2012) ont rapporté une augmentation de l'activité de l'hippocampe chez des personnes avec TCL suite à un entraînement de la mémoire associative, alors que cette région était hypoactive, avant l'intervention.

Bien que d'autres études restent à faire pour mieux comprendre la plasticité cérébrale chez les personnes atteintes de TCL, et entre autres, les liens entre le type d'entraînement cognitif reçu et les aires hyperactives retrouvées par la suite, les résultats obtenus jusqu'à maintenant indiquent que l'entraînement pourrait favoriser des processus de plasticité et de compensation même dans les stades précoces de la MA. Ces études indiquent également que la neuroimagerie fonctionnelle pourrait représenter un marqueur fiable et sensible pour rendre compte des effets des interventions cognitives utilisées chez des personnes TCL. D'ailleurs, Belleville et Bherer (sous presse) arrivent à la même conclusion dans une revue récente de la littérature portant sur l'utilisation de la neuroimagerie structurelle et fonctionnelle comme biomarqueur des effets des interventions dans le vieillissement normal et dans le TCL.

Conclusion

En conclusion, la neuropsychologie et les neurosciences cognitives – qui s'intéressent aux relations entre le cerveau et le comportement – peuvent assurément contribuer à la découverte de marqueurs sensibles et spécifiques afin de supporter un diagnostic précoce de la MA. Notamment, l'utilisation de certains tests neuropsychologiques mesurant les déficits de mémoire épisodique, de MdeT, des fonctions exécutives et de perception pourrait s'avérer des outils clés. Ensuite, bien que les techniques de neuroimagerie structurelle puissent identifier certains changements visibles sur le plan de l'anatomie du cerveau des gens atteints de TCL ou de la MA, il importe de complémenter ces observations par la caractérisation des changements d'activité cérébrale associées à la réalisation de tâches cognitives. En effet, en permettant d'aller au-delà de la structure, l'examen des activations fonctionnelles permet de déterminer les processus atteints et les mécanismes de compensation. Il a notamment permis d'identifier des phénomènes d'hyperactivation fonctionnelle qui pourraient refléter des processus de compensation ayant cours dans les stades précoces du TCL. Ainsi, il semble que la plasticité cérébrale soit présente naturellement dans les phases précoces de la MA, et que celle-ci puisse être modulée ou amplifiée par des techniques d'entraînement cognitif. Cette découverte est cruciale, car elle ouvre la voie à de nouveaux modes de traitement de la MA.

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Références

Amieva, H., Le Goff, M., Millet, X., Orgogozo, J. M., Pérès, K., Barberger-Gateau, P., . . . Dartigues, J. F. (2008). Prodromal Alzheimer's disease: successive emergence of the clinical symptoms. *Annals of Neurology, 64*(5), 492–498. doi:10.1002/ana.21509

Belleville, S., & Bherer, L., (in press). Biomarkers of cognitive training effects in aging. *Current Translational Geriatrics & Experimental Gerontology Reports*, doi:10.1007/s13670-012-0014-5.

Belleville, S., Chertkow, H., & Gauthier, S. (2007). Working memory and control of attention in persons with Alzheimer's disease and mild cognitive impairment. *Neuropsychology*, *21,* 458–459. doi:10.1037/0894-4105.21.4.458

Belleville, S., Clément, F., Mellah, S., Gilbert, B., Fontaine, F., & Gauthier, S. (2011). Training-related brain plasticity in subjects at risk of developing Alzheimer's disease. *Brain, 134*(6), 1623–1634. doi:10.1093/brain/awr037

Belleville, S., Gilbert, B., Fontaine, F., Gagnon, L., Ménard, É., & Gauthier, S. (2006). Improvement of episodic memory in persons with mild cognitive impairment and healthy older adults: Evidence from a cognitive intervention program. *Dementia and Geriatric Cognitive Disorders, 22*(5–6), 486–499. doi:10.1159/000096316

Belleville, S., Sylvain-Roy, S., de Boysson, C., & Menard, M. C. (2008). Characterizing the memory changes in persons with mild cognitive impairment. In W. S. Sossin, J.-C. Lacaille, V. F. Castellucci, & S. Belleville (Eds.). *Progress in Brain Research* (vol.169, chapitre 23, 365–375): Elsevier B.V.

Bier, B., & Belleville, S. (2010). Optimiser le fonctionnement cognitif au cours du vieillissement: facteurs de réserve, stimulation cognitive et plasticité cérébrale. *Neuropsicologia Latinoamericana*, *2*, 37–47.

Bondi, M. W., Monsch, A. U., Galasko, D., Butters, N., Salmon, D. P., & Delis, D. C. (1994). Preclinical cognitive markers of dementia of the Alzheimer type. *Neuropsychology*, *8*, 374–384. doi:10.1037/0894-4105.8.3.374

Celone, K. A., Calhoun, V. D., Dickerson, B. C., Atri, A., Chua, E. F., Miller, S. L., . . . Albert, M. S. (2006). Alterations in memory networks in mild cognitive impairment and Alzheimer's disease: An independent component analysis. *Journal of Neuroscience*, *26*, 10222–10231. doi:10.1523/JNEUROSCI.2250-06.2006

Clément F., & Belleville, S. (2010). Compensation and disease severity on the memory-related activations in mild cognitive impairment. *Biological Psychiatry*, *68*, 894–902. doi:10.1016/j.biopsych.2010.02.004

Clément, F., & Belleville, S. (2012). Effect of disease severity on neural compensation of item and associative recognition in mild cognitive impairment. *Journal of Alzheimer's Disease*, *29*, 109–123. doi:10.3233/JAD-2012-110426

Clément, F., Belleville, S., & Mellah, S. (2010). Functional neuroanatomy of the encoding and retrieval processes of verbal episodic memory in MCI. *Cortex*, *46*, 1005–1015. doi:10.1016/j.cortex.2009.07.003

Clément, F., Gauthier, S., & Belleville, S. (in revision). *Executive functions in mild cognitive impairment: Emergence and breakdown of neural plasticity*. Manuscript submitted for publication.

Devanand, D. P., Pradhaban, G., Liu, X., Khandji, A., De Santi, S., Segal, S., . . . Stern, Y. (2007). Hippocampal and entorhinal atrophy in mild cognitive impairment: Prediction of Alzheimer disease. *Neurology*, *68*, 828–836. doi:10.1212/01.wnl.0000256697.20968.d7

Devous, M. D. (2002). Functional brain imaging in the dementias: role in early detection, differential diagnosis, and longitudinal studies. *European Journal of Nuclear Medicine and Molecular Imaging. 29*, 1685–1696. doi:10.1007/s00259-002-0967-2

Dickerson, B. C., Salat, D. H., Bates, J. F., Atiya, M., Killiany, R. J., Greve, D. N., . . . Sperling, R. A. (2004). Medial temporal lobe function and structure in mild cognitive impairment. *Annals of Neurology*, *56*, 27–35. doi:10.1002/ana.20163

Fleisher, A. S., Sun, S., Taylor, C., Ward, C. P., Gamst, A. C., Petersen, R. C., . . . Thal, L. J. (2008). Volumetric MRI vs clinical predictors of Alzheimer disease in mild cognitive impairment. *Neurology, 70*, 191–199. doi:10.1212/01.wnl.0000287091.57376.65

Fratiglioni, L., Paillard-Borg, S., Winblad, B. (2004). An active and socially integrated lifestyle in late life might protect against dementia. *The Lancet Neurology*, *3*, 343–353. doi:10.1016/S1474-4422(04)00767-7

Ganguli, M., Dodge, H. H., Shen, C., & DeKosky, S. T. (2004). Mild cognitive impairment, amnestic type: An epidemiologic study. *Neurology*, *63*, 115–121. doi:10.1212/01.WNL.0000132523.27540.81

Gilbert, B., Fontaine, F., & Belleville, S. (2007). MÉMO: Méthode d'Entraînement pour une Mémoire Optimale.

Hampstead, B. M., Stringer, A. Y., Stilla, R. F., Deshpande, G., Hu, X., Bacon Moore, A., & Sathian, K. (2010). Activation and effective connectivity changes following explicit-memory training for face-name pairs in patients with mild cognitive impairment: A pilot study. *Neurorehabilitation and Neural Repair*, *25*, 210–222. doi:10.1177/1545968310382424

Hampstead, B. M., Stringer, A. Y., Stilla, R. F., Giddens, M., & Sathian, K. (2012). Mnemonic strategy training partially restores hippocampal activity in patients with mild cognitive impairment. *Hippocampus*, doi:10.1002/hipo.22006

Katzman, R., Terry, R., DeTeresa, R., Brown, T., Davies, P., Fuld, P., . . . Peck, A. (1988). Clinical, pathological, and neurochemical changes in dementia: A subgroup with preserved mental status and numerous neocortical plaques. *Annals of Neurology, 23*, 138–144. doi:10.1002/ana.410230206

Landau, S. M., Harvey, D., Madison, C. M., Reiman, E. M., Foster, N. L., Aisen, P. S., . . . Weiner, M. W. (2010). Comparing predictors of conversion and decline in mild cognitive impairment. *Neurology*, *75*, 230–238. doi:10.1212/WNL.0b013e3181e8e8b8

McKhann, G., Drachman, D., Folstein, M., Katzman, R., Price, D., & Stadlan, E. M. (1984). Clinical diagnosis of Alzheimer's disease. Report of the NINCDS-ADRDA work group under the auspices of the Department of Health and Human Services Task Force on Alzheimer's Disease. Neurology, *34(7)*. 939–944. doi:10.1212/WNL.34.7.939

McKhann, G. M., Knopman, D. S., Chertkow, H., Hyman, B. T., Jack, C. R., Kawas, C. H., . . . Mayeux, R. (2011). The diagnosis of dementia due to Alzheimer's disease: Recommendations from the National Institute on Aging-Alzheimer's Association workgroups on diagnostic guidelines for Alzheimer's disease. *Alzheimer's & Dementia, 7*(3), 263–269. doi:10.1016/j.jalz.2011.03.005

Petersen, R.C. (2003). *Mild cognitive impairment: aging to Alzheimer's disease*. Oxford, UK: University Press.

Prvulovic, D., Van de Ven, V., Sack, A. T., Maurer, K., & Linden, D. E. J. (2005). Functional activation imaging in aging and dementia. *Psychiatry Research*, *140*(2), 97–113. doi:10.1016/j.pscychresns.2005.06.006

Ritchie, K. (2004). Mild cognitive impairment: an epidemiological perspective. *Dialogues in Clinical Neuroscience*, *6*, 401–408.

Schwindt, G. C., & Black, S. E. (2009). Functional imaging studies of episodic memory in Alzheimer's disease: a quantitative meta-analysis. *Neuroimage*, *45*, 181–190. doi:10.1016/j.neuroimage.2008.11.024

Sperling, R. (2007). Functional MRI Studies of Associative Encoding in Normal Aging, Mild Cognitive Impairment, and Alzheimer's Disease. *Annals of the New York Academy of Sciences, 1097*, 146–155. doi:10.1196/annals.1379.009

Stern, Y. (2002). What is cognitive reserve? Theory and research application of the reserve concept. *Journal of the International Neuropsychological Society*, *8*, 448–460. doi:10.1017/S1355617702813248

Stern, Y., Habeck, C., Moeller, J., Scarmeas, N., Anderson, K. E., Hilton, H. J., . . . Van Heertum, R. (2005). Brain networks associated with cognitive reserve in healthy young and old adults. *Cerebral Cortex*, *15*, 394–402. doi:10.1093/cercor/bhh142

Villain, N., Chételat, G., Desgranges, B., & Eustache, F. (2010). Neuroimagerie de la maladie d'Alzheimer : Synthèse et apport à la compréhension des mécanismes physiopathologiques. *Biologie Aujourd'hui*, *204*, 145–158. doi:10.1051/jbio/2010010

Villeneuve, S., & Belleville, S. (2010). Réserve cognitive et changements neuronaux associés au vieillissement. *Psychologie et NeuroPsychiatrie du Vieillissement*, *8*, 133–140. doi:10.1684/pnv.2010.0214

Villeneuve, S. & Belleville, S. (2012). The nature of memory failure in mild cognitive impairment: Examining association with neurobiological markers and effect of progression. *Neurobiology of Aging*, 33(9), 1967–1978. doi:10.1016/j.neurobiolaging.2011.10.004

Wilson, R. S., Mendes De Leon, C. F., Barnes, L. L., Schneider, J. A., Bienias, J. L., Evans, D. A., & Bennett, D. A. (2002). Participation in cognitively stimulating activities and risk of incident Alzheimer disease. *Journal of the American Medical Association*, *287*, 742–748. doi:10.1001/jama.287.6.742

Annexe II : Article 4

Opportunities for virtual reality in cognitive training with persons with mild cognitive impairment or Alzheimer's disease

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ABSTRACT

The present review discusses the current and potential applications of virtual reality as a tool in cognitive intervention programs with people with Alzheimer's disease and mild cognitive impairment. Alzheimer's disease is a neurodegenerative disease characterised by cognitive deterioration including memory difficulties. Mild cognitive impairment is currently identified as a pre-clinical phase of dementia which includes cognitive decline that is more significant than cognitive changes observed in healthy aging, but does not meet criteria for Alzheimer's. Current clinical and investigative approaches often use cognitive training paradigms as intervention treatments aimed at slowing cognitive decline in these clinical populations. Cognitive training programs often used controlled laboratory settings with paper and pencil tasks or computer interfaces; however, such programs are not necessarily ecologically sound. Tasks used during training do not guarantee that the observed improvements will carry over to the individual's daily activities. As such, the development of virtual reality cognitive training platforms may bridge the gap between individual task performance and real-life benefits. Differences in the definition and equipment used for virtual reality have been observed in the literature, most notably in the degree or quality of immersion and interactivity within the virtual environment. As such, most findings on intervention programs with people with dementia are limited to interactive computer-based training paradigms, and virtual reality is currently more utilised in rehabilitation settings. However, the use of this new technology as a cognitive intervention with dementia has many possibilities, as well as limitations, that will be described.

Keywords: virtual reality, interactive computer training, mild cognitive impairment, Alzheimer's disease, cognitive intervention, cognitive training programs, PWA.

INTRODUCTION

The need for effective cognitive intervention programs for age-related cognitive decline is ever-increasing as the elderly demographic grows across the globe. Effective programs should be capable of being implemented early on within people with pre-clinical and clinical dementia. Furthermore, it is essential that the application of such intervention programs demonstrate real and measurable impact in improving activities in everyday life.

This challenge presents an opportunity to incorporate innovative tools into training programs for this population. Notably, the current technological improvements in virtual reality (VR) have the potential to be expanded into the treatment of cognitive decline. Integrating these technologies in intervention programs might have a considerable impact on how those intervention programs transfer their effect to challenges and limitations experienced by the elderly in their everyday life.

Mild Cognitive Impairment and Alzheimer's Disease

Alzheimer's disease (AD) is a neurodegenerative disease that affects a large number of older adults. The scale of the disease incurs a hefty social and economic cost that increases as the population ages (for a full discussion of disease facts and figures, see the Alzheimer's Association Report of 2011). There is increasing interest for the earliest phases of AD because it would allow for interventions to be made before the symptoms further escalate into full-blown dementia (Belleville, 2008). In this way, research on the characterization of Mild Cognitive Impairment (MCI) is a stepping-stone for approaching early diagnosis, as many with MCI eventually progress to AD or other dementias (Petersen & Morris, 2005; Gauthier et al., 2006). The criteria proposed by Petersen were for many years those that were most broadly used for MCI. They included a memory complaint confirmed by objective measurements with no significant impact on functional autonomy. Winblad and colleagues (2004) have later extended those criteria to include the distinction among the types of MCI, be it with or without memory impairment, or whether there is impairment in one or multiple cognitive domains. Recently, the National Institute on Aging and the Alzheimer's Association has adopted updated clinical criteria for MCI (Albert et al., 2011). They include changes in cognition, impairment in at least one cognitive domain, and mild difficulties in abilities to carry out complex daily tasks that previously did not present any challenges. Furthermore, this update includes criteria for assessing the strength of the diagnosis (degree of certainty) based on biomarkers.

Cognitive Intervention Programs in MCI and AD

In order to slow down the cognitive and memory declines experienced in AD and in MCI, there has been much development and research utilizing cognitive training programs.

These programs are created with the intention of improving cognitive capacities, slowing cognitive deterioration and/or to optimize functioning in daily living. Such programs may include cognitive stimulation, cognitive rehabilitation, or cognitive training (Clare et al., 2005; Belleville, 2008). Each of these types of interventions are further elaborated upon below in order to illustrate how each has different goals in practice. However, it should be mentioned that the distinction is not always clear-cut as there is often an overlap of their components.

Cognitive stimulation includes programs whereby individuals become involved in various activities, which may help overall cognition and social functioning in an enjoyable way (for a recent meta-analysis see Woods et al., 2012). A wide-range of activities have been used in such programs such as games (Cheng, Chan, & Yu, 2006), cued or guided group discussion (Breuil et al., 1994; Spector et al., 2003), and reality-orientation therapy (Patton, 2005). *Cognitive Rehabilitation* has an individualized approach and focuses more directly on improving functioning on specific everyday tasks (for review see Manzine & Pavarini, 2009). For example, an intervention might be devised to reinstate a hobby or activity that was given up by a person with dementia because of apathy or because it has become too difficult (Bier et al., 2011; Van der Linden, Juillerat, & Delbeuck, 2004). The benefit of this approach is that the needs of the individual can be accommodated in a very closely monitored therapy. Finally, the goal of *cognitive intervention* programs is to learn strategies and abilities in order to optimize their cognitive functioning (for a review, see Lustig, Shah, Seidler, & Reuter-Lorenz, 2009). Such intervention programs are often employed in studies with MCI, because those individuals have the capabilities to learn and retain new strategies and because they have the potential to generalize such learning to different situations and contexts (for a discussion, see Belleville, 2008). Cognitive intervention programs may focus on one particular function, such as attention (Gagnon & Belleville, 2012), or memory (Hampstead et al., 2011). They might also focus on multiple cognitive functions and/or include social or educational factors (Belleville et al., 2006; Belleville, Clement, & Mellah, 2011; Troyer et al., 2008).

Several intervention studies have demonstrated the success of cognitive training programs in AD and MCI when measured with laboratory tests of memory or cognition (for reviews see: Belleville, 2008; Buschert, Bokde, & Hampe, 2010; Jean, Bergeron, Thivierge, &

Simard, 2010; Simon, Yokomizo, & Bottino, 2012). However, one important challenge is related to their ecological validity and how much impact or transfer they have in daily life.

Ecological Validity and Transfer in Daily Life: A Challenge for Current Cognitive Training Programs

Ecological validity refers to the degree to which behaviors obtained in controlled experimental conditions are related to those obtained in a naturalistic environment (Tupper & Cicerone, 1990). According to Franzen and Wilhelm (1996), ecological validity can be addressed through two aspects: *verisimilitude* and *veridicality*. Verisimilitude refers to the degree of similarity between the cognitive demands of an experimental condition and the cognitive demands in the everyday environment. Verisimilitude is thus indicative of the "representative" capacity of the experimental condition. Veridicality refers to the extent to which performance measures in the experimental condition are correlated empirically to the measures of everyday functioning (Franzen & Wilhelm, 1996). "Functional validity" is another term that is used to represent this concept.

There are some limitations of the ecological validity within current cognitive training paradigms used with MCI/AD populations. First of all a verisimilitude problem can be observed: the naturalistic environment – where learned strategies have to be applied – is not very analogous to the laboratory setting, where strategies are learned. The laboratory environment, unlike the real environment, is "typically quiet, with few distractions, the examiner prompts task initiation and completion, provides one-on-one instruction, is supportive regardless of success or failure, and the tasks are typically novel, short, and require completion of one task at a time" (see Chaytor & Schmitter-Edgecombe, 2003). In addition, many cognitive intervention programs train participants on tasks that do not resemble day-to-day tasks (for example, lists of words to memorize or visual targets to detect) and utilize computer tasks that may be unfamiliar for older adults. The lack of verisimilitude of the laboratory setting highlights a potential problem regarding the generalizability of these interventions. Essentially, *far transfer*, or transfer of acquired learning between two dissimilar contexts (e.g., laboratory setting to real life) is rarely obtained in a spontaneous way (Barnett & Ceci, 2002). In order to optimize the likelihood of transferring cognitive training to real life scenarios, the incongruence between the two environments has to be reduced to allow *near transfer*, that is transfer to similar contexts (Barnett & Ceci, 2002).

Secondly, veridicality is also lacking in cognitive training programs with MCI/AD. The memory improvement observed via episodic memory outcome measures is rarely examined in relation with actual improvement of memory performance in daily living. In their review Stott and Spector (2011) examined how memory interventions in individuals with MCI can improve functioning in everyday life. Only a few of the interventions reported in MCI were able to generalize the improvements beyond the scope of the test measures to functioning in real-life. Furthermore, many of them used participant self-reporting post-intervention to measure real-life generalization, and these measures, the authors argue, do not always reflect actual improvements. Self-reports of performance may not accurately correspond to reality, and persons with MCI are not always the most reliable sources regarding their abilities. This problem of veridicality of outcome measures may be explained by the lack of verisimilitude of these same outcome measures: outcome measures (e.g., memory for word-lists, face-name associations with 2-D pictures of unknown individuals, etc.) hardly resemble day-to-day tasks. In other words, in spite of the evidence that these tasks are theoretically-motivated, reliable measures that are effective in demonstrating improvements, it is difficult to demonstrate that such gains can transfer to real-world benefits. In daily living, individuals are faced with a myriad of complex and challenging tasks that require different degrees of cognitive efficiency or refinement.

In sum, there is a need to include more ecologically valid content in the intervention programs that are offered to MCI/AD populations and in the measures used to test their efficacy. Many of the cognitive programs are designed and/or administered in a setting that is remote from the environments where older adults need to improve in their functioning. This highlights the challenges for ecological validity of trainings and generalizability of these interventions. Also, tasks used in typical training programs may not be practical for participants who see little relation between training and the real-world application of the strategies. Thus, the actual impact of intervention in everyday living is not yet well-known or rather limited for MCI or AD. It is quite possible that a major issue is the lack of appropriate outcome measures to assess daily functioning.

It is for all these reasons that a shift towards intervention programs that take into account the actual challenges faced by older adults, individuals with MCI and AD in real life would be an improvement. In addition to programs that approximate real-life, there is need for a shift towards objective outcome measures that are also more ecological. Advances in technology, such as innovations in virtual reality, are permitting the development of more applicable cognitive training designs.

Overview of Virtual Reality

According to Saposnik and Levin (2011), VR is a "[...] computer-based technology that allows users to interact with a multisensory simulated environment [...]" This definition implies that VR includes both user immersion and interaction within the VR environment created. Therefore the VR environment would enable users to model the environment according to the individual's needs and competencies. The VR environment is reactive and adaptable to the person's behavior. Similarly, Fuchs and colleagues (2006) defines VR as a technique or technology that allows the user to be immersed in an artificial environment (either imaginary or simulating real-life) within which it is possible to interact using behavioural interfaces. The key idea within these two definitions is that VR necessitates both an immersive and interactive virtual setting.

Interaction vs. Immersion

Interaction refers to the capacity of the virtual environment to be adjusted as a function of the user's actions. According to different authors (Burkhardt, 2003; Fuchs et al., 2006), *interaction* with the environment can occur through sensory interfaces: visually (presentation via screen or computer screen, VR glasses), via sound (headpiece or headphones), or even smell (olfactometer). Motor or movement interfaces allow the user to move through and interact with the setting through motion capture devices (from the basic computer mouse and joystick, all the way to eye-tracking and motion capture video). For instance, if a user perceives the virtual environment projected visually via VR glasses (Head Mounted Displays), the view of the environment has to change or correspondingly adjust whenever the user moves his head in order to be considered ''interactive''. In the same manner, if a user selects an object in a virtual environment through the use of an interface (e.g., with handheld button), this object has to react or respond to the choice of the user in order to depict interaction. In sum, when the virtual setting is capable of changing based on the input of the user (through the sensory-motor devices) then there is an actual interactive quality to the virtual environment.

According to Fuchs and colleagues (2006), interaction within the virtual environment is a necessary criteria for virtual reality. When there is no sensory-motor interaction between the user and the environment, the technology has a virtual environment but does not have actual VR.

Immersion on the other hand is defined as the degree to which the user is engaged in or surrounded by the virtual environment (Slater, 1999). Degree of immersion will usually depend on how rich or lifelike sensations and stimuli are rendered and will determine the extent to which participants can shut out sensations from the "real world". The technology used to present the environment varies, from using a computer displaying 2D or 3D images, all the way to 3D stereoscopic glasses that restrict vision to the virtual world and this will determine to a large extent the degree of immersion with the 3D stereoscopic glasses allowing the greatest degree of immersion.

Immersion can also be defined in terms of subjective psychological experience (Witmer & Singer, 1998): the more the individual is engaged within the scenario, the more his or her interactions will feel real and immersive. According to Steuer (1992), the key to defining VR in terms of human experience rather than technological hardware is the concept of *presence*: the user feels that he is in the environment and can act in.

The term VR has been used to describe a range of technologies that vary in the degree of immersion and interaction with a virtual environment. Complete VR would imply a fully immersive and interactive environment, whereas Interactive Computer Training (ICT) programs – which are frequently used in cognitive intervention studies – are typically less immersive in nature. In cognitive training programs resembling ICT, visual interfaces such as computer screens with joystick or mouse are most commonly used in the less immersive setting whereas devices that are worn over the eyes and head, such as stereoscopic glasses would be deemed more immersive. Our review of current VR studies uses such a broad perspective and examines cognitive training programs using technology that allows for the range of user interaction (those deemed VR or ICT).

To summarize, VR offers an infinite possibility of environments, and can be used to replicate real-life situations. As a result of this life-like potential, VR can be useful for cognitive training programs. This approach involves interventions that teach strategies to an individual in order to improve a specific or a range of cognitive functions. In this context, VR allows simulation of everyday life situations and can thereby focus on the particular challenges a person is experiencing when applying the learned strategies in real life. As is further discussed below, the applications for VR can therefore be integrated with existing intervention paradigms in MCI.

The Potential of VR for Cognitive Training

The use of VR in cognitive training in MCI/AD populations has many potential advantages. The technology has the potential to create training tasks with a higher degree of verisimilitude: with VR, training task can be performed in an immersive and interactive system resembling real-life experience. Ecological tasks, when used for training particular cognitive functions, are more likely to transfer cognitive gains into everyday living. Furthermore, including VR with training could be more interesting and motivating in that it resembles real activities and works on the individual's actual difficulties. The person can easily understand the usefulness and relevance of the treatment and strategies learned, in comparison with classical cognitive training, and can therefore be more invested in the procedure.

There are other advantages of VR for cognitive training. VR offers well-controlled environments that can be manipulated to cater the specific goals of the intervention sought. This allows control of task difficulty and isolation of the targeted function. Virtual environments also provide a secure setting for participants to work in – even one with cognitive deficits. For example, it is possible to create scenarios in which participants can safely practice driving without the risks and added physical danger. VR is also very adaptable in that it allows for training to vary between different settings and stimuli. Practice of various abilities can take place in many situations (e.g., hospital, restaurant, street, etc.), while the actual training of the participant remains in the same place (i.e., laboratory). This flexibility is practical especially with older adults and PWD or pre-dementia who may have reduced mobility.

The advantages of VR are also applicable toward its use as an outcome measure. VR provides the opportunity to objectively evaluate the benefits obtained during cognitive training in an ecologically-relevant (higher degree of verisimilitude) environment, and to assess the degree to which the gains transfer to real improvements in ecologically-relevant tasks in a flexible and secure environment. Through the use of this kind of measure, the degree of veridicality is likely to be strengthened, meaning that the correlation between performance in outcome task and the everyday functioning will be greater. It is also possible that there may be potential drawbacks of VR, and as such, these pitfalls are discussed in the limitations sections.

Research in VR As an Evaluative Tool for Cognitive Functions

VR is sometimes used as an evaluative tool for different cognitive functions, whether it is in the immersive or non-immersive form (environment displayed on a computer or wall-mounted screen). Among other things, non-immersive VR has proven to be an interesting method for evaluating spatial memory in healthy adults (Jian et Li, 2007) as well as adults with depression (Gould et al. 2007). In general, participants are asked to navigate in cities or locate predetermined destinations. In the latter study, this method was shown to be a more sensitive measure for spatial memory than traditional paper/pencil cognitive tests. Non-immersive VR has also demonstrated effectiveness for episodic spatial memory evaluation in healthy older adults (Plancher, Nicolas, & Piolino, 2007) and those with MCI and AD (Plancher, Tirard, Gyselinck, Nicolas, & Piolino, 2012). In these tasks, participants would be familiarized with an environment which they navigated via virtual car and later were tested for their recognition of details in the environments. With MCI and AD, this non-immersive VR task demonstrated greater sensitivity compared to traditional validated tools for episodic memory assessment, and was correlated with self-reported memory difficulties of participants.

VR has also been used for assessing prospective memory in individuals with traumatic brain injuries (TBI; Brooks, Rose, Potter, Jayawardena, & Morling, 2002). One study suggests that executive functions in persons with TBI can be measured with greater precision or sensitivity using non-immersive VR compared to traditional tools (McGeorge et al., 2001). In this study, participants with difficulties in planning participated in virtual and real errand-planning tasks. The results indicated that overall performance on both kinds of tasks were significantly correlated, demonstrating the validity of the virtual setting. Furthermore, measuring navigational attention is equally promising with non-immersive VR for MCI and AD (Drzezga et al., 2005) as well as healthy adults (Parsons & Rizzo, 2008).

Another study by Neider and colleagues (2011) used a virtual street-crossing to compare older and younger adults on a dual-task, an important cognitive function and a highly ecological measure. Participants were instructed to cross a street under three different distraction conditions: while listening to music, having a conversation on a hands-free device, or without any distraction (single-task condition). The participants walked on interactive treadmills that were synchronized to the intersection displayed (which included vehicles and traffic). As expected, compared to younger adults, older adults had greater dual-task performance costs in that they took longer to begin crossing and were more likely to stop and not complete the crossing, especially in the dual-task scenarios. This study illustrates the successful use of highly realistic VR with older adults on a task that is ecological and simultaneously physical and cognitive in nature.

These different applications of VR for evaluation purposes demonstrate that it is possible to use this technology in order to measure a variety of cognitive functions among an array of populations. Yet, very few studies have used VR as an outcome measure of cognitive training programs. However, in order to use these as outcome measures for MCI and AD populations, it will be critical to examine the psychometric properties of these tasks. We will need to know if they are reliable by measuring their test-retest properties. We will need to validate them in populations of older adults and it will be necessary to know if they are sensitive to change. Thus, intensive psychometric work will be required to integrate these tools as outcome measures for cognitive training programs.

Research in VR Training

As there is presently very little research on MCI using VR in cognitive intervention programs, it is worth highlighting the use of VR in studies with other populations first. Studies of younger adults in the domain of spatial memory using training with non-immersive VR are plentiful (Attree et al., 1996; Brooks, Attree, Rose, Clifford, & Leadbetter, 1999; Peruch, Vercher, & Gauthier, 1995; Wallet et al., 2011). These studies have shown that active exploration in a virtual environment (where participants control movements using a joystick) can result in improved spatial memory compared to passive exploration (where participants do not control their movements). Rose and colleagues (1999) observed similar results in individuals following a stroke (*n*: healthy control = 48, stroke = 48). These results indicate that cognitive training for spatial memory in VR with the capacity for active exploration improves performance. It is unclear based on these studies whether this training can be generalized to improving overall spatial memory or if it is limited to the environment used in training. To that end, some studies (e.g., Wilson, 1999) found no difference in spatial memory in healthy young adults (*n* = 24) after active or passive exploration of a VR environment. Despite this result, there is sufficient evidence that active exploration of a virtual environment is more useful for spatial learning than passive exploration.

Brooks and colleagues (1999) used non-immersive environment in a case study of one person with amnestic syndrome following a stroke. The authors found that the participant could navigate routes after being trained to actively navigate and learn two virtual environments. These improvements did not occur when the individual was trained for the actual routes in the hospital without the virtual environment. The authors suggest that training in the virtual setting was more effective because (1) it avoided irrelevant stimuli, (2) it allowed for more numerous practices than the real setting because the route could be completed faster, without movement difficulties, and (3) it facilitated backward movements in the route. These results are interesting, as they demonstrate that cognitive training in VR can lead to improvements in real settings and that it may in fact be more effective than training in real situations. However, a limitation of this study is that the environment included a reduction of ‘‘irrelevant’’ stimulation, and therefore the improvement was observed but not in an entirely ecologically valid VR environment, since a more ‘‘true to life’’ environment does often include superfluous stimuli.

A study by Cromby, Standen, Newman and Tasker (1996) further illustrated that gains made in training with VR can be transferred into real situations. The authors trained 19 persons with severe mental retardation either to shop (searching and retrieving selected items from a list) in a virtual supermarket (store displayed on a computer screen and navigated via mouse or joystick) or in a real one. The time to complete the task and look for items, as well as the number of items successfully brought to checkout were measured in both setting. After the training, the virtual-trained group performed the task faster and more accurately than the group trained in the actual supermarket setting. VR research has also been used in motor rehabilitation for individuals following a stroke (Broeren et al., 2004; Deutsch, 2011). It is becoming a very useful tool for stroke rehabilitation due to the immersive feedback that VR incorporates allowing participants to relearn and regain movement in a safe way (for a meta-analysis of stroke VR rehabilitation outcomes see Saposnik & Levin, 2011).

In healthy older adults, there is some more recent research surrounding the link between physical training and cognition that utilise immersive and interactive VR. For example, Anderson-Hanley and colleagues (2012) used a "cybercycling" task where older adults trained on stationary bicycles while navigating virtual tours displayed. Compared with the traditional physical exercise (control) group, the older adults who "cybercycled" for three months with the same effort demonstrated greater cognitive improvements. Specifically, the older adults from the experimental group improved more than controls on measures of executive functions. This study incorporates evidence of potential benefits of physical activity on maintenance of cognitive function. The study also employs – and demonstrates a benefit of using – a virtual environment that is both interactive and immersive, all while using a navigation which is a cognitive task.

VR dual-tasking may be a promising tool for cognitive-motor interventions with older adults. For example, training on a dance video game with distractors improves elderly balance, step-initiation (Pichierri et al., 2012) and may also improve attentional capacities. The research so far with older adults provides a new promising direction in terms of adapting VR not only to the elderly but to more cognitive programs (as opposed to simple physical/motor training). Studies with young adults, suggest that VR could yield benefits to memory performance. One example of this was observed by Pugnetti and colleagues (1998) who reported improvements in the incidental memory younger adults following a session of VR driving simulation. In another less interactive experiment examining spatial memory, Dinh and colleagues (1999) found that memory for object location and spatial layout was greater in healthy young participants who toured a highly realistic VR office environment (detailed rendering of rooms, which included matching smells and sounds) compared to participants in the less realistic scenarios. Although these studies were not conducted as memory interventions, they demonstrate life-like application of the technology and its potential for memory improvement.

Thus, studies using VR have shown potential to increase the efficacy of training programs meant to improve spatial navigation, executive functioning, or motor functioning in clinical participants (stroke, TBI) (Broeren et al., 2004; Deutsch, 2011; Jacoby et al., 2012) in healthy adults (Holper et al., 2010), and older adults (Anderson-Hanley et al., 2012). In turn, few studies exist in which cognitive tasks are the focal point. Furthermore, the VR designs described above have not yet been applied to groups of individuals with MCI and AD. It is foreseeable that the results observed in these other clinical groups may be extended in the future to persons with MCI and AD. If the spatial memory and navigation training benefits the other groups then it is possible it will improve these cognitive domains in older adults who have memory decline. Non-immersive programs, however, have been applied to these clinical populations and will be discussed in the following section.

Non-Immersive Cognitive Intervention Programs (with ICT) in AD and MCI

The few studies that have examined AD using ICT suggest that this type of cognitive training is capable of improving certain cognitive functions in this population. Hofmann, Hock and Müller-Spahn (1996) customized a touch-screen computer task to the individual needs and routines of four people diagnosed with AD. Each computer task differed in difficulty level and the cognitive component being trained (e.g., social competence vs. orientation vs. emotion) depending on the status of impairment of the person. The task incorporated pictures describing each successive step required to complete a given task – such as shopping in the orientation task – and the person had to navigate through the steps by pressing the appropriate region of the picture. Carried out via computer touch screen, this kind of ICT program is highly interactive, though it lacks the immersive component of VR. After having completed the training sessions performance on individual training tasks improved on the trained task but not on psychometric tests. One interesting aspect of this study however was to show that the participants were motivated in their tasks and that they reacted positively to the training experience in spite of the fact that they experience severe cognitive difficulties.

In another study of individuals with both vascular dementia and AD (n = 14), Schreiber and colleagues (1999) utilised a more interactive computer-based training program. In order to improve visual memory for objects and topographical memory over ten sessions, the participants were trained to locate objects and rooms while navigating through an apartment presented on the screen using a joystick. Once again, the task was interactive through the use of the joystick, but the computer presentation reduced the immersive quality. Training included an immediate and delayed retention component where participants were instructed, for example, to locate an object or room right away, or to *re*locate such previous targets again. The level of difficulty was adapted (number of targets to locate) gradually for each participant, based on their ability. This ICT program demonstrated improvements in memory compared to the participants in the control condition, who received social stimulation only.

Within a similar framework, Hofmann and colleagues (2003) adapted their training on activities of daily living to an interactive computer training program. Using a touch screen displaying photographs of shopping excursion, participants (AD n = 9; age- and gender-matched participants with a major depressive episode n = 9; and healthy control n = 10) were trained to navigate a supermarket to find and purchase three items. Touch navigation of the environment displayed seems to be an interactive task, but, once again, is not a fully immersive setting. The route and steps required for this plan were predetermined with the participant in order to be learned during the 12 training sessions. Upon completion of the training the authors found that the number of errors made during the task significantly diminished and these results were maintained for three months after the program. In a pilot study with two healthy older adults, Gadler, Grassi and Riva (2009) found improvements in orientation and attention following an ICT program. Optale and colleagues (2001; 2010) suggest that training of particular cognitive functions in older adults, with AD or certain memory deficits, is effective with these interactive virtual settings.

Immersive Cognitive Intervention Programs (with VR) in AD and MCI

Very few studies have implemented immersive and interactive VR environment in cognitive training programs for older adults. Optale and colleagues (2001, 2010) published two studies (the former is a case study, the latter $n = 36$) relying on VR for cognitive training in older adults and memory-impaired populations. Both studies alternated between presentation of auditory stimuli and virtual environments through headpieces without limiting the mobility of the participants. Participants listened to stories in order to remember their own personal memories. These stories could then be recalled while the participants navigated through virtual streets of a modern city. Following this, participants were instructed to describe their experience aloud referring to the environments connected to the various situations. In this way, the participants learned to navigate and orient themselves as the environments gradually increased in their complexity. After completing the sessions, participants reported better memory for names, dreams from sprevious nights, and words in conversation. Neuropsychological tests further supported the reduction of deficits and increase in memory performance (2001, 2010). These results indicate potential in integrating cognitive training tasks with VR for certain cognitive functions and in everyday functioning.

One problem that remains is that comparisons between non-VR interventions and VR or ICT (or) have not been directly studied. There is therefore no clear and definitively tangible support that VR provides more effective intervention and transferable cognitive gains than more classical types of intervention.

ICT, VR and fMRI

Functional magnetic resonance imagery (fMRI) allows observation of neural activity in the brain in real-time through a measure of the blood-oxygen-level dependent (BOLD) signal. This form of brain imaging has been used to study functional changes following cognitive training in persons with MCI (Belleville et al., 2011; Hampstead et al., 2011). Typically, the magnetic field generated by the MRI limits the inclusion of tools otherwise used in behavioural (non-imaging) studies because metallic devices are incompatible with MRI use. Recently, however, technological advances have led to the development of fMRI compatible VR kits. By combining VR with fMRI our understanding of the functional roles of various brain regions on cognition can improve. No longer constrained by traditional fMRI designs, the combination of VR and fMRI has the potential to incorporate research paradigms of higher complexity.

Since virtual reality in fMRI is a relatively new technology, not many studies on individuals with MCI and AD have been published thus far. For example, Hampstead et al. (2012) presented a virtual house during an fMRI task where the brain activations related to the associative encoding of items in healthy older adults and persons with MCI were measured. The house contained nine different rooms presented on a monitor and participants had to memorize the location of the items in each room. The results indicated lower memory scores as well as lower BOLD activation in various memory-related regions during encoding in MCI (n = 18) compared to healthy older adults (n = 16).

The use of VR in fMRI may also have possible applications for clinical case evaluations. VR in fMRI may also contribute toward designing innovative experiments that could impact intervention studies. For example, Hassadis et al. (2009) used a VR environment to study in more details the role of the hippocampus in spatial memory. The VR task consisted of navigating through two rooms of different colors. Each room had similar objects such as doors and paintings. Participants were asked to move between four different positions marked by rugs. At those locations, the angle in view would shift downward so that no spatial cues would be visible during the fMRI imaging acquisition. The authors conducted a multivariate pattern analysis and discovered that a participant's position in a room could be deduced from the hippocampal activity. Furthermore, activity in the parahippocampal gyrus could discriminate between the two rooms. Another study by Antonova et al. (2009) also studied spatial navigation and memory during fMRI. Here participants used a joystick to move in a virtual arena, and the authors examined activation during encoding, retention and retrieval of the individual's movement position in relation to physical markers present in the field of view. Overall, these results illustrate the unique contribution of VR/fMRI to assess in a more naturalistic manner the functional neural organization of the brain.

Another possible contribution of virtual environments in fMRI lies in its potential to shed light on the changes in activation associated with tasks that resemble everyday skills. In one case study, Campbell et al. (2009) compared activation associated with a VR/fMRI planning task and to an fMRI Tower of London test. The planning task consisted of navigating a virtual city presented on a monitor via joystick. Participants were asked to move from point A to point B, but had to adapt their route as a result of road blocks. The results demonstrated a certain degree of overlap between the activations elicited by the Tower of London test and the VR planning tasks as well as activations specific to each individual task. Overall, the Tower of London task recruited a broader range of neural networks and elicited stronger activations. While only a case study, the results suggest that VR could be used to develop ecological equivalent of classical neuropsychological tests that are better adapted for assessing real life behaviors.

The studies described above illustrate potential uses of fMRI/VR paradigms and their possible application for intervention studies. For example, the use of VR in the fMRI can shed light on the brain mechanisms that are involved when a participant uses the learned strategies in a complex or naturalistic environment. Thus, combining VR and fMRI offers promising research opportunities. The inclusion of VR in fMRI paradigm is still a new technique. Advancements in technical knowledge will undoubtedly provide new research avenues and garner a wider interest among researchers.

Limitations of VR

The use of VR as an effective tool in cognitive intervention for individuals with memory decline, including those with MCI and AD, may be on the horizon. However, its design development and validation as a measure remain the major steps before it can be routinely implemented. For example, there is not standardization of how an interactive and immersive technology capable of simulating the real-world should be shaped and constructed for intervention purposes. This can be a benefit, in that this tool is adaptable to fit the needs of a user (experimenter, clinician, and clinical group), however it can create incongruent results if not systematically programmed for all users. The VR environment is completely dependent on the choices of its creator.

Furthermore, previous psychometric measures (such as reaction times) may not be important for measuring how effective an intervention is, and as a result clinicians may need to come to a consensus on what constitutes objective cognitive improvements, as well as if and how changes can be reliably measured.

The large costs and space required for most VR programs present some disadvantages towards the use of the technology for training programs (Le Gall & Allain, 2001). It can be challenging and expensive to employ a team of professionals adept at maintaining and adapting the environments for different tasks. Additionally, participants using VR tasks sometimes report nausea or motion sickness (Regan, 1995; Pugnetti et al., 1996). In order to avoid ‘‘cyber-sickness’’, the immersion with the VR environment may have to be relatively short in duration. The use of VR with an elderly population presents another challenge. Firstly, cyber-sickness seems to increase with age in VR (Liu, Watson, & Miyazaki, 1999). Furthermore, although older adults are adapting to technological advances, many are less familiar with computers and other new technological devices compared to than younger individuals and may take longer to master the tools (Broady, Chan, & Caputi, 2010). Finally, the physical limitations often experienced by the elderly can impact their ability to remain standing for periods of time. Further adaptations of the tasks and virtual environments for older adults will be necessary in order to allow seated participation without reducing the degree of interaction and immersion.

There are also challenges related to designing appropriate VR environment, and various programming constraints can make the environment relatively rigid. VR has the potential to suggest reality or approximate real-world conditions, but it is also a simplified and controlled simulated environment that is completely dependent on its creator's choices. As a result, the major hurdles or restrictions to consider in VR for intervention have to do with the program's design and how developers need to be mindful to how the VR is built. Developers will need to consider, for example, whether there is a measurable continuum between tasks based on simple paradigms and those in VR. The reliability and validity of responses in VR will have to be assessed, as well as whether the theoretical approach to measurement needs to be modified. The latter point is important because we have to determine whether the approaches for response measurement typically used in other contexts will be applicable and *relevant* for VR. For example, what user-interactions will be considered "good" performance in VR (i.e., the use of reaction time, a stimulus-response paradigm?). This remains unclear because it is not yet known whether VR can affect the way a simple task is perceived, and if that in turn will impact the kinds of responses one makes in a VR environment. Should there be difficulties in measuring or interpreting the significance of simple responses then it will be even more challenging to do so for more complex behavioral responses and with strategies in VR. Approaches on how to best develop VR programs for intervention and rehabilitation are therefore still undefined.

When building a VR intervention program, developers will also have to determine the environments that are most practical and manageable for clinical groups, such as MCI and AD users and those that could benefit the most from life-like training. For example it would be practical to use or program commonly used environments such as a local park or grocery store that individuals may already recognize, or to work towards improving the image quality of the locales. Furthermore, another limitation of VR is that it can induce negative sensations during the user's experience such as anxiety, disorientation, and lack of familiarity due to the computerized or schematic nature of the VR environment. In order to alleviate these potential negative experiences familiarization with VR may be needed for participants to become accustomed and feel more at ease. As such, pre-training could be an important step for implementing these programs in order to ensure that the individuals become familiar with the stimuli (i.e., visual items and surroundings they might not be used to), setup, technology, as well as the physical sensations associated with VR. This will diminish possible negative effects of using high-level technology with particular groups. In the immersive environments investigators will have to examine the sensation of strangeness and how it may relate to the outcomes of the virtual setting (in other words, the impact of sensations such as anxiety and disorientation on the outcome measures and interaction in VR).

Approaches using VR are gradually becoming more refined, but investigators have not yet developed specific theories concerning how VR environments for rehabilitative and intervention purposes should be developed. However, some significant steps in this direction are being presently undertaken in order to understand how users engage in VR settings, (e.g., Cameirao et al., 2010; Gaggioli, 2012). In VR rehabilitation, Cameirao and colleagues (2010) demonstrated that a VR environment can be made to adapt to the needs and difficulty level for each individual, and that the movements used in the virtual task were consistent with those used in the real physical tasks. The users of VR programs have also indicated generally positive and pleasurable experiences that require a deep level of concentration (Gaggioli, 2012).

CONCLUSION

In sum, the literature discussed suggests that the development of VR as a tool for intervention is a promising technology. Researchers within the field of dementia and aging can potentially benefit from the use of VR as a method of cognitive training. In this way, training programs can become more ecologically valid and thereby translate the cognitive gains achieved in laboratory and hospital settings to actual improvements in functioning.

It is known that some more traditional cognitive training tasks are effective in improving episodic memory through laboratory tasks for individuals with MCI and AD, it is probably not necessary to entirely replace all current training methods with VR paradigms. Moreover, as mentioned in the previous section, currently VR paradigms pose many theoretical and design questions and limitations (such as the need for shorter session time in order to avoid nausea).

However, the use of VR could be used to bolster traditional cognitive training programs, and thus potentially resolve their primary weakness – transference of the cognitive benefits to everyday life. VR can provide complimentary information as an outcome measure with more traditional tests. Traditional measures of cognition remain important to assess specific cognitive process. In turn, VR can be used to measure the benefits in more contextually relevant areas of everyday life. It may become possible to more precisely estimate the transference from task improvements to real-world improvement.

Finally, it is evident that further investigations are necessary in order to completely measure the effectiveness of VR as a cognitive training paradigm. It must be emphasized that currently there is little research on truly immersive and interactive VR in *cognitive* interventions for memory in aging. Although the technology has arguably been in existence for some time, its application to this field is relatively recent and still developing. Researchers must still determine what the most essential variables to include in a virtual environment are:

what kinds of virtual environments work best for older adults and MCI/AD populations, types of tasks and their durations, degree of immersion and interaction, and the complexity of the environment etc. All of these elements will impact the training results and the ability for improvements to carry over into functioning in everyday life. Also, using VR tasks as outcome measures will require a great deal of work and research in order to create appropriate tasks and to validate them. Ultimately, more research is needed in order 1) to determine if such VR programs will offer more benefits to the cognitive training paradigms currently employed as interventions for deficits and 2) to assess if VR outcome measures can be more effective for evaluating daily function compared to classical outcomes of daily functioning.

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REFERENCES

Alzheimer's Association, 2011 Alzheimer's Disease Facts and Figures, *Alzheimer's & Dementia,* Volume 7, Issue 2.

Anderson-Hanley, C., Arciero, P. J., Brickman, A. M., Nimon, J. P., Okuma, N., Western, S. C., . . . Zimmerman, E. A. (2012). Exergaming and older adult cognition: A cluster randomized clinical trial. *American Journal of Preventive Medicine*, *42*, 109–119. doi:10.1016/j.amepre.2011.10.016

Antonova, E., Parslow, D., Brammer, M., Dawson, G. R., Jackson, S. H., & Morris, R. G. (2009). Age-related neural activity during allocentric spatial memory. *Memory*, *17*, 125–143. doi:10.1080/09658210802077348

Attree, E. A., Brooks, B. M., Rose, F. D., Andrews, T. K., Leadbetter, A. G., & Clifford, B. R. (1996). Memory processes and virtual environments: I can't remember what was there, but I can remember how I got there. Implications for people with disabilities. Paper presented at the *First European Conference on Disability, Virtual Reality and Associated Technologies*, Maidenhead, Royaume-Uni.

Barnett, S. M., & Ceci, S. J. (2002). When and where do we apply what we learn? A taxonomy for far transfer. *Psychological Bulletin, 128*(4), 612–637. doi:10.1037//0033-2909.128.4.612

Belleville, S. (2008). Cognitive training for persons with mild cognitive impairment. *International Psychogeriatrics*, *20*, 57–66. doi:10.1017/S104161020700631X

Belleville, S., Clément, F., Mellah, S., Gilbert, B., Fontaine, F., & Gauthier, S. (2011). Training-related brain plasticity in subjects at risk of developing Alzheimer's disease. *Brain, 134*, 1623–1634. doi:10.1093/brain/awr037

Bier, N., Macoir, J., Joubert, S., Bottari, C., Chayer, C., Pigot, H., & Giroux, S. (2011). Cooking ''shrimp à la créole'': A pilot study of an ecological rehabilitation in semantic dementia. *Neuropsychological Rehabilitation*, *21*, 455–483. doi:10.1080/09602011.2011.580614

Bouchard, S., & Côté, S. (2008). Virtual reality exposure for phobias: A critical review. *Journal of CyberTherapy and Rehabilitation*, *1*, 75–91.

Broady, T. Chan, A. & Caputi, P. (2010). Comparison of older and younger adults' attitudes towards and abilities with computers: Implications for training and learning. *British Journal of Educational Technology*, *41*(3), 473–485. doi:10.1111/j.1467-8535.2008.00914.x

Brooks, B. M., Attree, E. A., Rose, F. D., Clifford, B. R., & Leadbetter, A. G. (1999). The specificity of memory enhancement during interaction with a virtual environment. *Memory*, *7*, 65–78. doi:10.1080/741943713

Brooks, B. M., McNeil, J. E., Rose, F. D., Greenwood, R. J., Attree, E. A., & Leadbetter, A. G. (1999). Route learning in a case of amnesia: A preliminary investigation into the efficacy of training in a virtual environment. *Neuropsychological Rehabilitation*, *9*, 63–76. doi:10.1080/713755589

Brooks, B., Rose, F., Potter, J., Jayawardena, S., & Morling, A. (2004). Assessing stroke patients' prospective memory using virtual reality. *Brain Injury, 18*, 391–401. doi:10.1080/02699050310001619855

Burkhardt, J.-M. (2003). Réalité virtuelle et ergonomie : quelques apports réciproques. *Le travail humain, 1*, 65–91. doi:10.3917/th.661.0065

Cameirão, M. S., Badia, S. B., Oller, E. D., & Verschure, P. F. (2010). Neurorehabilitation using the virtual reality based Rehabilitation Gaming System: Methodology, design, psychometrics, usability and validation. *Journal of Neuroengineering and Rehabilitation, 7*(1), 48, 1–14. doi:10.1186/1743-0003-7-48

Campbell, Z., Zakzanis, K. K., Jovanovski, D., Joordens, S., Mraz, R., & Graham, S. J. (2009). Utilizing virtual reality to improve ecological validity of clinical neuropsychology: An fMRI case study elucidating the neural basis of planning by comparing the Tower of London with a three-dimensional navigation task. *Applied Neuropsychology, 16*, 295–306. doi:10.1080/09084280903297891.

Chaytor, N., & Schmitter-Edgecombe, M. (2003). The ecological validity of neuropsychological tests: A review of the literature on everyday cognitive skills. *Neuropsychology review, 13*(4), 181–197. doi:10.1023/B:NERV.0000009483.91468.fb

Cromby, J., Standen, P., Newman, J., & Tasker, H. (1996). Successful transfer to the real world of skills practised in a virtual environment by students with severe learning difficulties. In P. Sharkey (Ed.), *Proceedings 1st European Conference on Disability, Virtual Reality, and Associated Technologies* (pp. 103–107). Maidenhead, UK: The University of Reading.

Deutsch, J. E. (2011). Using Virtual Reality to Improve Walking Post-Stroke: Translation to Individuals with Diabetes. *Journal of Diabetes Science and Technology, 5*(2), 309–314. doi:10.1177/193229681100500216

Dinh, H. Q., Walker, N., Hodges, L. F., Song, C., & Kobayashi, A. (1999, March). Evaluating the importance of multi-sensory input on memory and the sense of presence in virtual environments. In *Virtual Reality, 1999. Proceedings., IEEE* (pp. 222-228). IEEE.

Drzezga, A., Grimmer, T., Peller, M., Wermke, M., Siebner, H., Rauschecker, J. P., . . . Kurz, A. (2005). Impaired Cross-Modal Inhibition in Alzheimer Disease. *PLoS Med, 2*(10), e288. doi:10.1371/journal.pmed.0020288

Fuchs, P., Moreau, G., Burkhardt, J.-M., & Coquillart, S. (2006). *Le traité de la réalité virtuelle - Volume 2. L'interfaçage, l'immersion et l'interaction en environnement virtuel*, Transvalor - Presses des Mines.

Gadler, E., Grassi, A., & Riva, G. (2009). A rehabilitation protocol for empowering spatial orientation in MCI. A pilot study. *Annual Review of CyberTherapy and Telemedicine, 7*, 234–236. doi:10.3233/978-1-60750-017-9-234

Gaggioli, A. (2012). Quality of experience in real and virtual environments: Some suggestions for the development of positive technologies. *Annual Review of CyberTherapy and Telemedicine,* 177–181. doi:10.3233/978-1-61499-121-2-177

Gauthier, S., Reisberg, B., Zaudig, M., Petersen, R. C., Ritchie, K., Broich, K., . . . Cummings, J. L. (2006). Mild cognitive impairment. *The Lancet*, *367*(9518), 1262–1270. doi:10.1016/S0140-6736(06)68542-5

Gould, N. F., Holmes, M. K., Fantie, B. D., Luckenbaugh, D. A., Pine, D. S., Gould, T. D., . . . Zarate, C. A. Jr., (2007). Performance on a virtual reality spatial memory navigation task in depressed patients. *American Journal of Psychiatry, 164*(3), 516–519. doi:10.1176/appi.ajp.164.3.516

Hampstead, B. M., Sathian, K., Phillips, P. A., Amaraneni, A., Delaune, W. R., & Stringer, A. Y. (2012). Mnemonic strategy training improves memory for object location associations in both healthy elderly and patients with amnestic mild cognitive impairment: A randomized, single-blind study. *Neuropsychology, 26,* 385–399. doi:10.1037/a0027545

Hampstead, B. M., Stringer, A. Y., Stilla, R. F., Deshpande, G., Hu, X., Moore, A. B., & Sathian, K. (2011). Activation and effective connectivity changes following explicit-memory training for face–name pairs in patients with mild cognitive impairment: A pilot study. *Neurorehabilitation and Neural Repair*, *25*(3), 210–222. doi:10.1177/1545968310382424

Hassabis, D., Chu, C., Rees, G., Weiskopf, N., Molyneux, P. D., & Maguire, E. A. (2009). Decoding neural ensembles in the human hippocampus. *Current Biology, 19*(7), 546–554. doi:10.1016/j.cub.2009.02.033

Hofmann, M., Hock, C., & Müller-Spahn, F. (1996). Computer-based Cognitive Training in Alzheimer's Disease Patients. *Annals of the New York Academy of Sciences, 777*(1), 249–254. doi:10.1111/j.1749-6632.1996.tb34427.x

Hofmann, M., Rösler, A., Schwarz, W., Müller-Spahn, F., Kräuchi, K., Hock, C., & Seifritz, E. (2003). Interactive computer-training as a therapeutic tool in Alzheimer's disease. *Comprehensive Psychiatry, 44*(3), 213–219. doi:10.1016/s0010-440x(03)00006-3

Holper, L., Muehlemann, T., Scholkmann, F., Eng, K., Kiper, D., & Wolf, M. (2010). Testing the potential of a virtual reality system during performance of observation, imagery and imitation of motor actions recorded by wireless functional infrared spectroscopy (fNIRS). *Journal of NeuroEngineering and Rehabilitation*, *7*, 57–69. doi:10.1186/1743-0003-7-57

Jacoby, M., Averbuch, S., Sachar, Y., Katz, N., Weiss, P., & Kizony, R. (2012). Effectiveness of executive functions training within a virtual supermarket for adults with traumatic brain injury: A Pilot Study. *IEEE transactions on neural systems and rehabilitation engineering*: *A publication of the IEEE Engineering in Medicine and Biology Society*, *21*(2), 182–190.

Jean, L., Bergeron, M. È., Thivierge, S., & Simard, M. (2010). Cognitive intervention programs for individuals with mild cognitive impairment: Systematic review of the literature. *American Journal of Geriatric Psychiatry, 18*(4), 281–296. doi:10.1097/JGP.0b013e3181c37ce9

Jiang, C.-F., & Li, Y.-S. (2007). *Virtual hospital–a computer–aided platform to evaluate the sense of direction.* Paper presented at the Engineering in Medicine and Biology Society, EMBS 2007. 29th Annual International Conference of the IEEE, Lyon, France.

Kessels, R. P. C., van Doormaal, A., & Janzen, G. (2011). Landmark recognition in Alzheimer's dementia: Spared implicit memory for objects relevant for navigation. *PLoS One, 6,* e18611. doi:10.1371/journal.pone.0018611.

Le Gall, D., & Allain, P. (2001). Applications des techniques de réalité virtuelle à la neuropsychologie clinique. *Champ Psychosomatique*, *2*, 25–38. doi:10.3917/cpsy.022.0025

Liu, L., Miyazaki, M., & Watson, B. (1999). Norms and validity of the DriVR: A virtual reality driving assessment for persons with head injuries. *CyberPsychology & Behavior, 2*, 53–67. doi:10.1089/cpb.1999.2.53

Liu, L., Watson, B., & Miyazaki, M. (1999). VR for the elderly: Quantitative and qualitative differences in performance with a driving simulator. *CyberPsychology & Behavior*, 2(6), 567–576. doi:10.1089/cpb.1999.2.567

Luo, J. S. (2007). Virtual reality therapy: On your desktop today. *Primary Psychiatry*, *14*, 20–22.

McGeorge, P., Phillips, L. H., Crawford, J. R., Garden, S. E., Sala, S. D., Milne, A. B., . . . Callender, J. S. (2001). Using virtual environments in the assessment of executive dysfunction. *Presence: Teleoperators & Virtual Environments*, *10*(4), 375–383. doi:10.1162/1054746011470235

Moffat, S. D. (2009). Aging and spatial navigation: What do we know and where do we go? *Neuropsychology Review, 19*, 478–489. doi:10.1007/s11065-009-9120-3

Neider, M. B., Gaspar, J. G., McCarley, J. S., Crowell, J. A., Kaczmarski, H., & Kramer, A. F. (2011). Walking and talking: Dual-task effects on street crossing behavior in older adults. *Psychology and Aging*, *26*, 260–268. doi:10.1037/a0021566

Olazaran, J., Reisberg, B., Clare, L., Cruz, I., Pena-Casanova, J., Del Ser, et al. (2010). Nonpharmacological therapies in Alzheimer's disease: A systematic review of efficacy. *Dementia and Geriatric Cognitive Disorder, 30*, 161–178.

Optale, G., Capodieci, S., Pinelli, P., Zara, D., Gamberini, L., & Riva, G. (2001). Music-enhanced Immersive Virtual Reality in the Rehabilitation of Memoryrelated Cognitive Processes and Functional Abilities: A Case Report. *Presence: Teleoperators and Virtual Environments, 10*(4), 450–462. doi:10.1162/1054746011470217

Optale, G., Urgesi, C., Busato, V., Marin, S., Piron, L., Priftis, K., . . . Bordin, A. (2010). Controlling Memory Impairment in Elderly Adults Using Virtual Reality Memory Training: A Randomized Controlled Pilot Study. *Neurorehabilitation and Neural Repair, 24*(4), 348–357. doi:10.1177/1545968309353328

Parsons, T. D., & Rizzo, A. A. (2008). Neuropsychological Assessment of Attentional Processing using Virtual Reality. *Annual Review of Cybertherapy and Telemedecine*, *6*, 23–28.

Peruch, P., Vercher, J.-L., & Gauthier, G. M. (1995). Acquisition of spatial knowledge through visual exploration of simulated environments. *Ecological Psychology*, *7*, 1–20. doi:10.1207/s15326969eco0701_1

Petersen, R. C., & Morris, J. C. (2005). Mild cognitive impairment as a clinical entity and treatment target. *Archives of Neurology*, *62*, 1160–1163. doi:10.1001/archneur.62.7.1160

Pichierri, G., Coppe, A., Lorenzetti, S., Murer, K., & de Bruin, E.D. (2012). The effect of a cognitive-motor intervention on voluntary step execution under single and dual task conditions in older adults: A randomized controlled pilot study. *Clinical Interventions in Aging*, *7*, 175–184. doi:10.2147/CIA.S32558

Plancher, N., Nicolas, S., & Piolino, P. (2008). Apport de la réalité virtuelle en neuropsychologie de la mémoire : étude dans le vieillissement. *Psychologie et NeuroPsychiatrie du Vieillissement*, *6*, 7–22. doi:10.1684/pnv.2008.0119

Plancher, G., Tirard, A., Gyselinck, V., Nicolas, S., & Piolino, P. (2012). Using virtual reality to characterize episodic memory profiles in amnestic mild cognitive impairment and Alzheimer's disease: Influence of active and passive encoding. *Neuropsychologia, 50*(5), 592–602. doi:10.1016/j.neuropsychologia.2011.12.013

Pugnetti, L., Mendozzi, L., Attree, E. A., Barbieri, E., Brooks, B. M., Cazzullo, C. L., . . . Rose, D. F. (1998). Probing memory and executive functions with Virtual Reality: Past and present studies. *CyberPsychology & Behavior*, *1*, 151–161. doi:10.1089/cpb.1998.1.151.

Pugnetti, L., Mendozzi, L., Barbieri, E., Rose, F.D., & Attree, E.A. (1996). Nervous system correlates of virtual reality experience. In P.M. Sharkey (Ed.)*, Proceedings of the 1st European Conference on Disability, Virtual Reality and Associated Technology*, (pp 239–246). Maidenhead, UK: University of Reading.

Regan, C. (1995). An investigation into nausea and other side-effects of head-coupled immersive virtual reality. *Virtual Reality*, *1*, 17–32. doi:10.1007/BF02009710

Rose, F. D., Brooks, B. M., Attree, E. A., Parslow, D. M., Leadbetter, A. G., McNeil, J. E., . . . Potter, J. (1999). A preliminary investigation into the use of virtual environments in memory retraining after vascular brain injury: Indications for future strategy? *Disability and Rehabilitation*, *21*(12), 548–554. doi:10.1080/096382899297206

Schreiber, M. (1999). Potential of an interactive computer-based training in the rehabilitation of dementia: An initial study. *Neuropsychological Rehabilitation, 9*(2), 155–167. doi:10.1080/713755596.

Simon, S. S., Yokomizo, J. E., & Bottino, C. M. (2012). Cognitive intervention in amnestic Mild Cognitive Impairment: A systematic review. *Neuroscience & Biobehavioral Reviews, 36*(4), 1163–1178. doi:10.1016/j.neubiorev.2012.01.007

Slater, M. (1999). Measuring presence: A response to the Witmer and Singer presence questionnaire. *Presence: Teleoperators and Virtual Environments, 8*(5), 560–565. doi:10.1162/105474699566477

Stott, J., & Spector, A. (2011). A review of the effectiveness of memory interventions in mild cognitive impairment (MCI). *International Psychogeriatrics, 23*(4), 526–538. doi:10.1017/S1041610210001973

Troyer, A. K., Murphy, K. J., Anderson, N. D., Moscovitch, M., & Craik, F. I. (2008). Changing everyday memory behaviour in amnestic mild cognitive impairment: A randomised controlled trial. *Neuropsychological Rehabilitation, 18*(1), 65–88. doi:10.1080/09602010701409684

Van der Linden, M., Juillerat, A.-C., & Delbeuck, X. (2004). Cognitive rehabilitation in mild cognitive impairment and prodromal Alzheimer's disease. In S. Gauthier, P. Scheltens and J. Cummings (Eds.), *Alzheimer' s Disease and Related Disorders Annual* (pp. 81–96). London: Martin Dunitz.

Wallet, G., Sauzéon, H., Pala. P. A., Larrue, F., Zheng, X., & N'Kaoua, B. (2011). Virtual/real transfer of spatial knowledge: Benefit from visual fidelity provided in a virtual environment and impact of active navigation. *Cyberpsychology, Behavior, and Social Networking*, *14*(7–8), 417–423. doi:10.1089/cyber.2009.0187

Weniger, G., Ruhleder, M., Lange, C., Wolf, S., & Irle, E. (2011). Egocentric and allocentric memory as assessed by virtual reality in individuals with amnestic mild cognitive impairment. *Neuropsychologia*, *49*(3), 518–527. doi:10.1016/j.neuropsychologia.2010.12.031

Wilson, P. N. (1999). Active exploration of a virtual environment does not promote orientation or memory for objects. *Environment and Behavior, 31*, 752–763. doi:10.1177/00139169921972335

Winblad, B., Palmer, K., Kivipelto, M., Jelic, V., Fratiglioni, L., Wahlund, L. O., & Petersen, R. C. (2004). Mild cognitive impairment–beyond controversies, towards a consensus: Report of the International Working Group on Mild Cognitive Impairment. *Journal of internal medicine*, *256*(3), 240–246. doi:10.1111/j.1365-2796.2004.01380.x

Witmer, B. G., & Singer, M. J. (1998). Measuring presence in virtual environments: A presence questionnaire. *Presence: Teleoperators and virtual environments, 7*(3), 225–240. doi:10.1162/105474698565686

Annexe III : Article 5

Use of immersive virtual reality to assess episodic memory: A validation study in older adults

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ABSTRACT

Virtual reality (VR) allows for the creation of ecological environments that could be used for cognitive assessment and intervention. This study comprises two parts that describe and assess an immersive VR task, the Virtual Shop, which can be used to measure episodic memory. Part 1 addresses its applicability in healthy older adults by measuring presence, motivation, and cybersickness symptoms. Part 2 addresses its construct validity by investigating correlations between performance in the VR task and on a traditional experimental memory task, and by measuring whether the VR task is sensitive to age-related memory differences. Fifty-seven older and 20 younger adults were assessed in the Virtual Shop, in which they memorized and fetched 12 familiar items. Part 1 showed high levels of presence, higher levels of motivation for the VR than for the traditional task, and negligible cybersickness symptoms. Part 2 indicates that memory performance in the VR task is positively correlated with performance on a traditional memory task for both age groups, and age-related differences were found on the VR and traditional memory tasks. Thus, the use of VR is feasible in older adults and the Virtual Shop is a valid task to assess and train episodic memory in this population.

Keywords: virtual reality, episodic memory, aging, validation study, neuropsychological assessment.

Memory is a complex function that relies on a range of interacting processes and systems. A variety of experimental and clinical tasks has been devised to measure memory and to attempt to tease apart these different processes. For instance, different tasks and testing conditions have been developed to distinguish familiarity from recollection, item from associative memory, or memory for verbal, visual, or spatial material. Memory tasks traditionally used in clinical practice or those used in experimental studies of aging are constructed to allow a fine control of the task parameters and testing conditions to reflect these fine-grained processes. However, these tasks generally lack ecological validity, as they fail to reflect the complexity and diversity of memory situations that older adults experience in their daily lives (Bowman, 1996; Chaytor & Schmitter-Edgecombe, 2003; Farias, Harrell, Neumann, & Houtz, 2003; Piolino, Desgranges, & Eustache, 2009; Sbordonne & Long, 1996; Schultheis, Himelstein, & Rizzo, 2002; Shuchat, Ouellet, Moffat, & Belleville, 2012). In real life, memorizing often occurs in noisy environments with multi-dimensional material and often happens while completing other tasks, such as walking, talking, or problem solving. This is in marked contrast to the testing conditions that occur in experimental and clinical contexts, in which participants complete their tasks in quiet conditions, receive clear task instructions, encode unidimensional material most of the time and focus their attention on the task.

Virtual reality (VR) is a promising technology that could help increase the ecological validity of memory assessments and interventions. VR immerses the user in a dynamic virtual environment in which he/she carries out cognitive and sensorimotor activities while interacting with virtual stimuli (Fuchs, Moreau, & Berthoz, 2006). One major asset of VR is that it offers environments that reproduce the sensorial characteristics of the real world (e.g., visual scenes, audible conversations) and incorporate the cognitive and physical demands of situations that individuals face in their everyday lives. Thus, VR gives the opportunity to sample the integrity of cognitive functions in contexts that are more representative of everyday life.

These offer tremendous potential as measures of real-life cognition. Well-designed VR tasks might therefore better reflect real-life capacities than traditional neuropsychological tests (Rizzo, Schulteis, Kerns, & Mateer, 2004). Furthermore, VR has great potential to measure whether neuropsychological interventions transfer to daily life, which is a major challenge in rehabilitation studies (Adamovich et al., 2004; Lehmann et al., 2005; Ouellet, Boller, Corriveau-Lecavalier, Cloutier, & Belleville, 2018; Shuchat et al., 2012; Sveistrup, 2004).

However, VR is a recent technology, and so is its application to cognitive measurement. Many reasons justify measuring the applicability of VR in older adults. Studies using VR protocols with older adults are rare and hence many crucial questions regarding the applicability and validity of VR tasks among older adults remain to be investigated. Designing and testing tasks that reflect memory in real life is particularly interesting in the context of aging. Episodic memory declines with age, is frequently impaired by brain disease, and is one of the first signs of Alzheimer’s disease. Thus, having access to a variety of sensitive and valid tools to assess and train episodic memory is crucial for clinical neuropsychologists. Furthermore, while there are many well-designed tasks to measure the fine processes involved in episodic memory, VR can provide tools that reproduce the complexity of memory in daily life. This is critical, as the impact of cognitive decline on autonomy is a major concern in the context of age-related cognitive decline, and VR could contribute to addressing these issues. Yet, the feasibility and applicability of VR in older adults is a potential problem because of differences in technological literacy. As older adults are less likely to make use of information and communication technologies than younger adults (Selwynn, 2004), it is critical to study factors that might contribute to their subjective experience when placed in a VR environment, as well as potential barriers to the use of this technology.

This study will address the applicability of VR technology in a population of older adults and its potential application to memory assessment by measuring presence, motivation, and cybersickness symptoms with a fully immersive episodic memory task (Part 1). It will also assess its construct validity (Part 2). The following section will briefly introduce these notions and how they have been addressed in the literature.

Presence is defined as the subjective experience of being in a place when one is in fact physically in another one (Witmer & Singer, 1998). Thus, in the context of VR, it refers to the subjective experience of actually being in the environment that is represented. It is calculated with questionnaires measuring the quality of the interaction with the environment, whether the experience in the environment was consistent with the real-world experience, and the quality and ease of the interface. A number of factors might determine the magnitude of presence experienced by the participants. Some are related to the software and hardware characteristics of the VR environment, for instance the interface quality, the type of interaction (e.g., joystick vs button response), or how participants navigate in the environment (e.g., active vs passive navigation). Psychological factors related to the user can also contribute to presence and performance in VR. These include the participant's perception regarding the degree of realism of the task, the level of control they have over the situation, the possibility they have to examine the elements of the environment, their subjective evaluation of their own performance, and their general motivation with respect to the task. Measuring presence is critical. Numerous studies have found that presence is positively related to performance in normal young individuals. In younger adults, larger presence has been associated with better sustained attention (Witmer & Singer, 1998), psychomotor performance (Stevens & Kincaid, 2015; Witmer & Singer, 1994), and spatial memory (Bailey & Witmer, 1994). It was also found that VR conditions that reduce presence, for instance those with limited user-environment interactions or which rely on less natural environments, also have deleterious effects on performance (for a review, see Nash, Edwards, Thompson, & Barfield, 2000). The association frequently reported between presence and cognitive performance implies that conditions that create a higher sense of presence will be more likely to provide an optimal assessment of cognition. We therefore examined if the VR environment elicits an appropriate sense of presence in older adults and if the expected correlation is found between presence and performance.

The degree of motivation towards the task might be particularly relevant when designing VR environments, as motivation optimises performance and is related to resource allocation in older adults (Hess, 1994; Hess, Germain, Swaim, & Osowski, 2009; Hess, Popham, Emery, & Elliott, 2012). Because older adults are generally less technologically experienced, one might expect them to be less motivated by VR than by non-VR tasks. Interestingly, some results suggest that this may not be the case. In a study led by Benoit et al. (2015), participants were presented with a photograph or an image-based VR representation of familiar locations in their home city or new locations and were asked to indicate whether they recognised the location. The motivation level of older adults, which was measured with a homemade questionnaire, was found to be larger for the VR than for the non-VR version of the task, although the difference was non-significant. Using the same motivation questionnaire, Manera et al. (2016) reported that older adults with mild cognitive impairment or Alzheimer's disease actually experienced higher levels of satisfaction and security, and lower levels of anxiety, discomfort, and fatigue, during a highly realistic image-based VR cancellation task than during its paper–pencil version (Manera et al., 2015). Thus, both studies reported that older adults experience a higher level of motivation for the VR rather than the non-VR version of the same tasks. Though there is clearly a need for more empirical data, these preliminary findings are interesting and suggest that VR has the potential to elicit positive motivation in older adults.

Cybersickness is potentially a major limitation for the use of VR. Indeed, nausea, headaches, and disorientation can occur while immersed in a virtual environment (Jaeger & Mourant, 2001; Slater, 1999). Their occurrence could seriously hamper the applicability of VR technology in populations that are sensitive to these symptoms. A few studies have found more frequent cybersickness symptoms in older adults relative to younger ones, although the reported difference appears to be of a relatively small magnitude (Arns & Cerney, 2005; Liu, Watson, & Miyazaki, 1999). However, a more recent study reported no increase in cybersickness symptoms following immersion in older adults (Benoit et al., 2015).

Additionally, it is critical to know whether cognitive VR tasks reflect the construct that they are intended to measure. Construct validity refers to the capacity of a test to accurately reproduce the attributes and characteristics of a given construct (Cronbach & Meehl, 1955). Convergent validity is a type of construct validity and is determined by measuring whether performance on the VR task is related to performance on tasks that measure similar theoretical concepts. A few studies have addressed the convergent validity of VR tasks by comparing them with traditional tasks that assess the same cognitive processes. Studies in younger adults have generally reported significant correlations between VR and traditional tasks of inhibition (Armstrong et al., 2013; Henry, Joyal, & Nolin, 2012), and VR and traditional tasks of attention (Parsons & Courtney, 2014). Parsons and Rizzo (2008) reported positive correlations between a traditional word memory task and memory performance in a VR task in which younger adults had to recall a list of 10 items (e.g., a blue car) encoded while navigating a virtual city. Plancher, Nicolas, and Piolino (2008) and Jebara, Orriols, Zaoui, Berthoz, and Piolino (2014) found that older adults' performance on the recognition of items seen in a 2D VR car ride was positively correlated with performance on traditional recognition and executive tests, suggesting that the VR memory task may also reflect other cognitive capacities, such as executive processes.

Construct validity can also be assessed by examining whether a VR task is sensitive to the differences in episodic memory typically associated with aging. Previous studies have found age-related differences on the free recall of spatiotemporal characteristics of a list of items encoded during a virtual car ride (e.g., where and when the items were seen during the car ride; Plancher et al., 2008) and on the free recall of items presented in a virtual apartment

(Sauzéon et al., 2016). These results are broadly consistent with the literature, indicating that age is associated with a reduction of associative memory, defined as the capacity to bind pieces of information into a cohesive unit, and of episodic memory, defined as the memory for items encoded with their spatio-temporal context (Chalfonte, 1996; Johnson, 1996; Naveh-Benjamin, 1990; 2000).

In summary, VR has tremendous potential to measure memory in conditions that reflect cognition in everyday life. The use of VR might contribute greatly to how neuropsychologists assess cognition and provide interventions. Furthermore, the technology is becoming cheaper and more accessible, making its use with clinical populations likely to increase in the near future. However, there is a need for applicability and validation data to support VR as a useable technology in older adults and to ensure that VR variants of memory tasks reflect the constructs that they are meant to assess. The present study addresses these issues. The VR task developed here was meant to reflect a situation that is close to a real-life situation and likely reflects memory in action. Participants encode visually presented items and are then asked to find them in a small convenience store. As is the case in real life, their performance is probably based on a combination of active retrieval (for instance, “I need to go get the broom”) and recognition, because it is likely that some items are recognised as they walk in the virtual environment. Thus, the task is quite unique relative to traditional memory tasks because the objects are present in the environment, yet the task involves active search and interference. The task requires a conscious mental representation of the items to fetch, which is to some extent close to the process of free recall: participants probably evoke their list while walking around in the store. Although the objects were present and could be used as cues, the subjective experience is clearly more complex than a typical recognition task because participants move in the environment to search for the memorized objects rather than being passively presented with lists of potential items. Another major innovative aspect of the study is to rely on a fully immersive 3D VR technology. Relying on 3D VR technology differs markedly from computerised flat screen VR tasks in that it provides a more immersive experience and more natural interaction with the surrounding environment. However, the technology might be more challenging to use by older adults or clinical populations than 2D technology. To our knowledge, no study has investigated the VR feasibility using a fully immersive technology.

Part 1 addresses the applicability of a fully immersive 3D VR episodic memory task in which participants had to memorize and fetch a series of items in a Virtual Shop. This is addressed in younger and older adults by measuring presence, motivation, and cybersickness symptoms. We hypothesise that the task will show strong feasibility in both younger and older adults. We also anticipate that older and younger adults will show a comparable level of presence and that presence will be related to performance in the VR task (Bailey & Witmer, 1994; Witmer & Singer, 1994). We also expected that the task would be motivating for participants, irrespective of their age. Finally, we did not expect cybersickness symptoms to interfere with the task completion, as a number of studies have reported that older adults have relatively few symptoms of cybersickness with tasks of short duration.

Part 2 measures construct validity of the immersive VR episodic memory task by comparing performance on the VR task with that obtained from traditional paper-pencil memory tasks and measuring whether the VR task was sensitive to the age difference typically found in episodic memory. Given the results from prior work, we hypothesise that the task will be a valid representation of episodic memory capacities. We expect that the task will have appropriate construct validity. This will be supported by finding a positive correlation between memory performance on the VR task and performance on a traditional task measuring immediate and delayed free recall of a list of visually presented words. Construct validity will also be supported by findings of a lower VR memory performance in older adults compared to young adults.

General methods, common to Parts 1 and 2

Participants

The study included 57 cognitively healthy older adults and 20 younger adults. It included a larger number of older than younger adults, as older adults were the main focus of our study. The goal was to assess the applicability and validity of VR in this population, and younger adults were included as a group of comparison. Furthermore, inter-individual variability increases with age (Hultsch & MacDonald, 2004; Hultsch, Strauss, Hunter, & MacDonald, 2008) and thus including a larger number of older adults increased the power to detect a group difference. The same participants were used for both parts to increase power and because this facilitates the comparison of the results obtained for feasibility and validity. Participants were recruited from the local community and were all native French speakers. Exclusion criteria included the following: presence or history of a neurodegenerative disease, life-threatening disease (e.g., cancer), stroke, uncontrolled sleep apnea, major psychiatric disorders (i.e., depression, schizophrenia, etc.), excessive drinking (> 25 drinks per week; for equivalence, see http://www.ccdus.ca/Resource%20Library/2012-Canada-Low RiskAlcoholDrinkingGuideline-Brochure-en.pdf), substance abuse, general anaesthesia during the past 6 months, balance difficulties, uncorrected visual impairment, and important hearing loss (corrected or not). We also used the Montreal Cognitive Assessment (MoCA) (Nasreddine et al., 2005), a short cognitive assessment battery, to exclude older adults with impaired cognition (score ≤ 26). The RL/RI-16 word recall task (Van der Linden et al., 2004) was included to characterise verbal memory in the sample of older adults and facilitate comparison between this sample and other samples that will be used in future studies.

The participants' demographic and clinical characteristics are presented in Table 1. Older and younger adults were equivalent on demographic characteristics. Furthermore, the scores of the older adults on the neuropsychological tests were within the normal range when considering their age and education level. This was expected, given that cognitively impaired participants were excluded.

VR task

The virtual environment of the Virtual Shop (La boutique virtuelle) was developed and rendered using the 3DVIA Virtools 5 3D engine and was run on a Dell Precision T3600 PC with an Inter(R) Xeon (R) CPU ES-1620 0 (3.60 Ghz, 10 Gbytes in RAM) processor and a NVIDIA GeForce GTX600 Ti graphics card. It was designed in collaboration with Cliniques et développement in virtuo (www.invirtuo.com). The virtual environment was in 3D and the immersion was produced by an Nvisor ST50 audio-visual headgear and by a Worldviz PPT-X studio tracking system that allowed the participant to rotate his/ her head in a 360-degree view around the room, as well as look up and down, and interact and walk freely in the virtual environment. The participant was asked to stand in the empty assessment room while the assistant installed the headgear and hand device. He/she was then presented with the virtual environment. The environment was a small convenience store built using the same dimensions as the assessment room (3.5 m × 6.5 m). Participants were told that they were free to move around the environment, explore and fetch items. Participants used a hand remote control to select and retrieve items. The remote control allowed them to display a target sign that they could move in the virtual environment in order to point to the items they wanted to select.

Table 1

Demographic and clinical characteristic of participants

	Younger (N = 20)	Older (N = 57)
Age (years)	21.65 (2.46)	67.77 (7.03)
Education (years)	13.90 (2.05)	14.86 (3.23)
Gender (f, m)	13, 7	47, 10
Montreal Cognitive Assessment (MoCA) (/30)	-	27.58 (1.74)
RL/RI-16 word recall test (3rd free recall)	-	11.46 (2.31)
RL/RI-16 word recall test (delayed free recall) (/16)	-	12.11 (2.08)
Geriatric Depression Scale (GDS)	-	1.77 (2.73)

Participants began the task in front of a cashier working behind a countertop and were presented with a list of 12 familiar virtual images of common items (e.g., belt, milk) that they were asked to memorize and then fetch in the store (see Figure 1). Each item was visually presented for 5 s on a notepad situated on the countertop with the name of the item written below the image to ensure that the item was properly encoded. During encoding, irrelevant conversations were presented via the headgear in order to mimic a noisy environment. Following the presentation of the last item, the programme initiated a 20-s conversation between the cashier and the participant (e.g., Could you tell me the time, which is displayed on your right?) as a filled interference delay. At the end of the delay period, the cashier instructed the participant to fetch the items in the store he/she had previously seen. The participant could then walk freely in the room to find and select the items that were shown on the learning list. There were 24 items displayed in the shop: 12 target items and 12 distractors. We chose distractors that matched the targets by taxonomic category. This is relevant when designing episodic memory tasks, as memory errors most often preserve the category in free recall conditions and more errors are made when distractors share the same semantic category as the target in recognition conditions. Furthermore, this feature reduces the likelihood of simply guessing the correct item based on having encoded its semantic category. It therefore makes the task more sensitive to memory failures. An ancillary benefit to using semantic distractors is that it enhances the ecological value of the test, as real-life shopping often requires selecting items among other ones from the same category. For instance, if one has to buy a particular vegetable to make a soup, it will be found in the "fruit and vegetable section" of the supermarket and the person will therefore be faced with distractors from the same category. The items were located on the shelves, on the floor, or hung on the walls.

Participants used a hand remote control to select and retrieve the items and were given unlimited time to find them. Prior to the testing, they were familiarised with the virtual devices using a different version of the convenience store in a condition in which they were simply asked to walk in the virtual environment and select an item that was not used in the memory test. During this familiarisation phase, additional information and practice trials were given to participants who were unsure about the procedure of the task or with the operation of the remote control. Familiarisation was continued until the participant was comfortable with the manipulation of the material in order to reduce the likelihood that problems would occur during the VR task.

Correct performance was measured as the number of targets that were correctly retrieved. A false recognition error response was recorded when the participant selected an incorrect item; that is, one that was not part of the encoded list. Note that all foils are related to one of the presented items and, therefore, false recognition errors are semantic errors by design. There were other built-in parameters that were measured by the VR task; for instance, time before the first item was selected and total time to complete the task. Although they were not used in the present study, they could be useful for researchers interested in a more extensive characterisation of the participant's behaviour in the task (see, for instance, Ouellet et al., 2018).

Figure 1. The Virtual Shop

A

B

C

Figure 1. The Virtual Shop. Image A shows the notepad on the countertop, on which items appeared during the encoding phase, after which the cashier would talk to the participant as a filled interference delay. Image B shows a version of the Virtual Shop, with the items placed on the shelves and hung to the walls. Finally, Image C shows an item that has been selected by the participant with the remote control.

Traditional episodic memory task measures

A traditional experimental memory task was used to test convergent validity and compare motivation in a virtual vs non-virtual variant of a memory task. The task was adapted from a validated free recall word list test (Belleville et al., 2002). Two lists of 12 concrete words were visually presented on a laptop using e-prime. Two lists were used to increase the number of trials and, hence, reduce the impact of extraneous variables on performance. The lists were matched for word length (1–4 syllables), word frequency, and concreteness. Participants were presented with the words at a rate of one item every 5 s (4 s of presentation and 1 s of cross fixation). The lists were encoded and recalled with irrelevant verbal noise, similar to the noise used in the VR task, and were presented through a Plantronix Audio 550 headset. Participants were instructed to remember as many words as possible. Immediately after the presentation of the list, participants were asked to write down the words they remembered in the order in which they came to mind. Thus, participants did not have to retrieve the order in which items were presented, similar to what is typically done in clinical memory measures and as was the case for the VR task. Free recall was repeated 4 minutes after participants had completed a short-term memory task (a digit span task).

The use of an experimental measure was preferred over that of a clinical measure (for example, the logical memory test or the California Verbal Learning Test) as a test of convergent validity. This was done to allow for more flexibility and control over testing parameters. Using a computerised presentation facilitated strict control over presentation parameters (e.g., presentation rate, recall delay). Designing the task allowed us to control the frequency and concreteness of the items using data collected from the French-Canadian population. It also enabled us to match some of its parameters with those of the VR task (e.g., use of similar encoding rates, interfering noise during encoding, and a visual presentation of the stimuli). Note that the VR task is more complex by design and, hence, we did not expect a perfect match with the traditional task. One major difference relates to the retrieval phase. As is typical when shopping, items are retrieved while the participant walks in the VR environment and it is therefore more akin to a recognition than recall procedure. Thus, retrieval in the VR environment involves a mix of active search and recognition, while our traditional memory task involves recall.

Design

Health and demographic questionnaires were completed during a 30-min telephone interview. Eligible participants were tested with the cognitive and VR measures, and administered the presence, motivation, and cybersickness questionnaires at the CRIUGM during a single 2-hour session. Participants first received the traditional memory task, followed by the Motivation Questionnaire related to the traditional memory task and the cybersickness questionnaire. They then completed the VR task, followed by the cybersickness questionnaire for a second time, the motivation questionnaire related to the VR task, and the presence questionnaire. This study was approved by the Regroupement Neuroimagerie/Québec (RNQ) Comité mixte d'éthique de la recherche.

The French version of the Presence Questionnaire (Witmer & Singer, 1994), which was adapted by the Cyberpsychology Laboratory of the Université du Québec en Outaouais (UQO) (Robillard, Bouchard, Renaud, & Cournoyer, 2002), included 19 items (e.g., to what degree did your interactions with the environment seem natural?) divided into five subscales: realism, possibility to act, interface quality, possibility to examine, and self-evaluation of the performance. In this questionnaire, participants were asked to rate their VR experience on a Likert scale ranging from 1 (not at all) to 7 (completely). The questionnaire is constructed so that responses in the low range of the scale (1–3) indicate a negative experience, whereas responses in the high range of the scale (5–7) indicate a positive experience. This questionnaire was shown to have good internal consistency (Cronbach's alpha of 0.88), as well as content and construct validity (Witmer & Singer, 1994).

For the purpose of this study, we also constructed an experimental Motivation Questionnaire to assess motivation evoked by the tasks. The questionnaire was constructed based on a literature review regarding the different components of motivation according to the concept of flow (Csikszentmihalyi, 2000) in relation to video games (Klasen, Weber, Kircher, Mathiak, & Mathiak, 2012), and media enjoyment (Weber, Tamborini, Westcott-Baker, & Kantor, 2009). One version was used for the VR task and another for the traditional memory task. Each version comprised 7 items, against which participants rated their level of motivation and interest regarding the task they completed (e.g., I felt engaged during the task on the computer/Virtual environment) on a Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). Lower scores indicated a low level of motivation. The questionnaire showed an appropriate internal consistency when tested in this sample (Cronbach's alpha = 0.79).

The French version of the Simulator Sickness Questionnaire (Kennedy, Lane, Berbaum, & Lilienthal, 1993), which was adapted by the UQO Cyberpsychology Laboratory (Bouchard, Robillard, & Renaud, 2007), was used to assess the occurrence, nature, and severity of cybersickness symptoms when immersed in a virtual environment. Two subscales (nausea and oculomotor difficulties) included 16 items (e.g., headaches), against which participants had to rate their symptoms on a scale of 0 (not at all) to 3 (severely). Here, lower ratings correspond to low levels of symptoms. This questionnaire was found to have good internal consistency (Cronbach's alpha of 0.81), and to be a valid measure of motion-induced sickness symptoms (Kennedy et al., 1993).

Statistical analyses and results

The data were analysed using Statistical Package for Social Sciences (SPSS) version 21.0. Three older adults did not complete the entire protocol: two of them reported severe cybersickness symptoms and thus could not complete the VR task, and one participant withdrew from the study before the VR task. Participants who withdrew for cybersickness symptoms completed the Sickness Simulator Questionnaire after the VR task and were thus included in the analysis of cybersickness symptoms. As there were no significant differences in terms of education and gender distribution between the younger and older adults, it was not necessary to use them as nuisance covariates (Miller & Chapman, 2001).

In order to compare younger and older adults on different Presence Questionnaire subscales, independent t-tests (two-tailed) with significance levels set to $p < .01$ according to the Bonferonni correction for multiple comparisons were conducted, and Pearson bivariate correlations (two-tailed) were performed to investigate the relationship between the different Presence Questionnaire subscales and memory performance on the VR task. Comparisons were adjusted according to Levene's tests for homogeneity of variance when needed. A 2 (Type of task) × 2 (Group) ANOVA was used to assess the degree of motivation evoked by the different memory tasks in younger and older adults. To assess the magnitude of cybersickness symptoms, a 2 (Immersion)×2 (Group) ANOVA was conducted in order to compare younger and older adults before and after the immersion.

Presence

Results (means and standards deviations) for the Presence Questionnaire subscales, the Motivation Questionnaire for the VR and the traditional memory tasks, the Sickness Simulator Questionnaire, and performance on the VR and traditional memory task measures are listed in Table 2. Overall, participants rated the aspects related to the different Presence Questionnaire subscales in the positive range. No differences were found between the two groups on any of the subscales (realism, $t(1, 72) = 0.59$, $p = .60$; possibility to act, $t(1, 72) = 0.31$, $p = .76$; interface quality, $t(1, 72) = 0.40$, $p = .69$; possibility to examine, $t(1, 72) = 0.06$, $p = .95$; self-evaluation of performance, $t(1, 72) = 2.32$, $p = .29$).

In older adults, there were significant positive correlations between VR performance and all subscales of the Presence Questionnaire (realism, $r = 0.36$, $p < .01$; possibility to act, $r = 0.41$, $p < .01$; interface quality, $r = 0.42$, $p < .001$; possibility to examine, $r = 0.28$, $p < .05$; self- evaluation of performance, $r = 0.37$, $p < .01$). In younger adults, VR performance only correlated positively with the interface quality subscale, $r = 0.53$, $p < .05$, but there were no significant correlations with the other subscales (realism, $r = -0.27$, $p = .25$; possibility to act, $r = -0.01$, $p = .98$; possibility to examine, $r = -0.21$, $p = .37$; self-evaluation of performance, $r = -0.31$, $p = .18$).

Motivation

The ANOVA indicated a significant effect for the Type of task, as the motivation scores for the Virtual Shop were higher than for the traditional memory task for both groups, $F(1, 72) = 23.65$, $p < .001$, $\eta 2 = 0.25$. Results also revealed a Group effect, as older adults had higher motivation scores than younger adults overall, $F(1, 72) = 1132.37$, $p < .001$, $\eta 2 = 0.40$. There was no Group × Type of task interaction, $F(1, 72) \leq 1$, $p = .54$.

Table 2

Mean scores for the questionnaires and time to complete the VR task

	Younger (*N* = 20)	Older (*N* = 57)
Presence Questionnaire		
Realism (/49)	34.40 (6.18)	33.77 (7.50)
Possibility to act (/28)	19.40 (3.42)	19.32 (5.34)
Interface quality (/28)	14.50 (2.82)	15.17 (3.43)
Possibility to examine (/14)	13.85 (2.52)	14.17 (3.72)
Self-evaluation of performance (/14)	11.55 (2.06)	10.06 (2.82)
Motivation Questionnaires		
Virtual Reality (/35)	20.35 (7.50)	29.36 (5.16)
Traditional task (/35)	16.45 (7.97)	26.46 (5.14)
Sickness Simulator Questionnaire		
Pre-immersion		
Nausea (/27)	1.35 (3.76)	0.93 (1.33)
Oculo-motor difficulties (/21)	2.55 (2.46)	3.57 (2.39)
Total score (/48)	3.90 (5.42)	4.46 (3.24)
Post-immersion		
Nausea (/27)	2.75 (5.32)	2.73 (3.94)
Oculo-motor difficulties (/21)	3.05 (2.72)	2.95 (3.27)
Total score (/48)	5.80 (7.37)	5.67 (6.44)
Time to complete Task (seconds)	312.65 (99.17)	482.00 (153.30)

Cybersickness symptoms

There were slightly more cybersickness symptoms following than prior to immersion but the effect just missed significance, $F(1, 74) = 3.71$, $p = .06$. There was neither a Group nor interaction effect, $F < 1$, in both cases. Scores on the Sickness Simulator Questionnaire indicated that both groups experienced a low level of cybersickness symptoms, even after immersion.

Part II: Validation of the virtual shop

Method and results

The second part of this study assessed construct validity by computing Pearson bivariate correlations (two-tailed) to assess the relationship between performance on the VR task and on free immediate and delayed recall, measured with traditional word recall tasks in both younger and older adults (convergent validity). It also assesses construct validity by measuring whether the VR task was sensitive to the age-related effect typically observed on episodic memory tasks. Groups were compared on their performance on the Virtual Shop with independent t-tests (two-tailed), using the number of accuracies (correctly retrieved items) and the number of false recognitions as dependent variables. Their performance on the traditional memory task was compared with a 2 (Group) × 2 (Delay) ANOVA using correct word recall as the dependent variable.

Convergent validity

Performance on the VR task correlated with the immediate and delayed free recall scores of the traditional verbal memory task in both younger ($r = 0.57$, $p < .01$ and $r = 0.46$, $p < .05$, respectively) and older adults ($r = 0.28$, $p < .05$ and $r = 0.30$, $p < .05$, respectively) (see Table 3 for performance on the VR and traditional memory tasks).

Construct validity

As expected, results on the traditional memory task showed a Group effect, $F(1, 75) = 41.28$, $p < .001$, $\eta 2 = 0.36$, a Delay effect, $F(1, 75) = 62.52$, $p < .001$, $\eta 2 = 0.60$, and a Group × Delay interaction, $F(1, 75) = 13.37$, $p < .001$, $\eta 2 = 0.15$. Tukey post-hoc analysis revealed a stronger effect of delay in older than in younger adults, $p < .001$. The VR task was sensitive to age, as younger adults performed significantly better than older adults when using the number of correct answers as a dependent variable, $t(1, 73) = 2.38$, $p < .05$, $d = 0.30$. However, there was no group effect on the number of false recognitions, $t(1, 75) = 0.79$, $p = .94$.

Table 3

Mean scores for the memory tasks

	Younger (N = 20)	Older (N = 57)
Memory tasks		
The Virtual Shop		
Items correctly identified	9.10 (2.13)	7.66 (2.37)
False recognitions	1.14 (0.25)	0.66 (0.09)
Episodic immediate recall (/12)	7.68 (2.08)	5.28 (1.42)
Episodic delayed recall (/12)	6.73 (2.59)	3.32 (1.75)

Discussion

To our knowledge, this study is the first to address the applicability and validity of a fully immersive episodic memory VR task in younger and older individuals. Overall, results indicate that the VR technology is a useable tool in aging and that the Virtual Shop has adequate validity properties to reflect episodic memory in a virtual context. This indicates that the technology is suitable to assess, and eventually train, episodic memory in older adults. These aspects of the study are discussed below.

The first goal of the study was to assess the feasibility of the VR task. Our hypothesis was that the Virtual Shop would show strong feasibility in younger as well as older adults. All three indicators suggest good feasibility. The five subscales of the Presence questionnaire were positively rated by both age groups, and younger and older adults were comparable on all subscales. We found higher levels of motivation for the Virtual Shop than for the traditional memory task in both age groups. Finally, negligible cybersickness symptoms were found following immersion for both younger and older adults.

Hence, the fact that older adults might have been less exposed to technology and electronic devices does not seem to impact their capacity to feel comfortable in virtual environments, to experience similar feelings and reactions as in real-life situations, and to enjoy realising cognitive tasks in that sort of setting. Our environment was fully immersive, and the high degree of interaction could account for the high sense of presence (Slobounov, Ray, Johnson, Slobounov, & Newell, 2015) and to making it a more inviting and interesting experience than the traditional task. Furthermore, the resemblance of the Virtual Shop with everyday situations may have provided a more meaningful environment to older adults and contributed to our finding that younger and older adults experienced an equivalent level of presence and motivation. This is consistent with the literature reporting that presence is optimised by meaningful environments and by conditions that allow user-environment interactions (for a review, see Nash et al., 2000). The fact that presence was high and that all subscales of the presence questionnaire were positively related to performance in older adults indicates that the age effect in memory is not accounted for by a poor sense of presence. This result supports the use of VR as a valid measure of memory in older adults. Interestingly, though, performance in younger and older adults is influenced by different characteristics from the presence experience within VR. The performance of younger adults appears to be influenced by the task's interface quality, whereas that of older adults appears to be influenced by the task's interface quality but also by the content of the task as well as their personal appraisal and confidence with respect to the task. Thus, many dimensions related to presence appear to influence cognition measurement when using VR with older adults, and these should be taken into account when designing tasks adapted to this population. Importantly, this may not be particular to VR, as many of these characteristics have been shown to influence performance when testing older adults with traditional tools as well.

One frequently reported drawback regarding the use of VR in older adults is the fact that it elicits cybersickness and that these effects might be more frequent and/or severe in older adults. The number of cybersickness symptoms did not significantly increase following immersion. Nevertheless, the two age groups reported slightly more cybersickness symptoms following immersion and that the pre–post immersion effect was close to significance. Importantly, however, the Group×Immersion interaction was far from significance, which indicates that older adults were not more prone to cybersickness symptoms than younger adults. Furthermore, the reported level of cybersickness symptoms was relatively low. Thus, cybersickness symptoms slightly increased with immersion but did not hamper the completion of the VR task. Of note: our task was of a relatively short duration and hence whether participants would have experienced more cybersickness symptoms with longer durations remains to be determined.

The second part of the study measured the construct validity of the Virtual Shop. Our hypotheses regarding construct validity were that the memory performance in the Virtual Shop would be correlated to that obtained from a traditional verbal episodic memory task and that the task would be sensitive to age-related differences. Both hypotheses were confirmed. Performance in the VR task was positively correlated with performance in a traditional word-recall test, suggesting that both reflect verbal memory processes. This concurs with previous studies indicating that VR can measure similar constructs as those measured by clinical or experimental measures (Armstrong et al., 2013; Henry et al., 2012; Parsons & Courtney, 2014; Parsons & Rizzo, 2008; Plancher et al., 2008). This is an important finding. VR measures memory performance in complex conditions in the presence of auditory and visual distractions, and while the participant navigates the environment and manipulates new devices. Furthermore, older adults showed the typical age-related memory decrement when examining the number of correctly retrieved items as a dependent variable. This indicates that the VR task is sensitive to typical memory impairment.

However, it is important to stress that even if the traditional and VR tasks share some common variance, they also differ in many other ways. Importantly, retrieval phases differed markedly between the traditional tasks and the VR tasks. Indeed, the former was a recall task whereas the latter involved recognition, which are subtended by different cognitive and brain processes. Furthermore, the VR task involves retrieval in challenging conditions because the environment is noisy, and participants have to retrieve information while walking and selecting the objects. Other studies have shown that recognition is impaired in older adults when performed in attention-demanding conditions (Anderson, Craik, & Naveh-Benjamin, 1998; Li, Lindenberger, Freund, & Baltes, 2001). Hence, the Virtual Shop has the potential to unravel cognitive difficulties encountered by older adults in real life, when conditions are more distracting or more demanding.

The fact that our VR and traditional tasks share common variance but are not totally equivalent indicates that VR can have a unique contribution to memory assessment.

Traditional memory tasks can be used to isolate individual memory processes. In turn, VR tasks can provide a reflection of how memory works in real-life situations in which different processes interact to result in complex behaviour. VR memory measures such as the Virtual Shop are designed to reflect real-life memory and hence are quite complex tasks. Future studies should include a larger number of measures to address convergent criterion validity. It is indeed likely that other cognitive and sensorimotor processes other than memory contribute to performance in such complex immersive VR tasks.

Interestingly, the two age groups showed an equivalent number of false recognition errors. Thus, older adults omit more items than younger ones, but do not select erroneous semantic foils. This is contrary to some studies indicating that older adults have a more liberal response bias than younger ones (Dodson, Bawa, & Krueger, 2007; Huh, Kramer, Gazzaley, & Delis, 2006), but consistent with others reporting no age differences in response bias (e.g., see Bastin & Van der Linden, 2003). Interestingly, a yes–no recognition format similar to the one used here was found to yield a lower level of commission when compared to a forced-choice recognition format (Bastin & Van der Linden, 2003). In forced-choice recognition, the presence of concurrent alternatives would increase the likelihood of false-recognition errors. Thus, the finding of a similar number of false recognition in older and younger adults might be due to the fact that our recognition format is not one that favours this type of error.

Results must be interpreted within the context of some limitations. As stated above, it remains unclear whether other cognitive processes are implicated in the VR task, aside from episodic memory. Also, we have created a life-like task involving shopping in an immersive environment with demanding retrieval conditions and background noise. Our goal was to construct a task that would approximate real-life conditions, keeping in balance the limitations inherent to simulation procedures and to the technology involved in VR. Thus, it was not possible to make the VR and traditional memory tasks entirely equivalent. This was the case for the retrieval condition. Shopping in real life typically involves a relatively long delay between encoding (when one determines a list of items to buy) and retrieval (when one has arrived at the place where those items will be purchased). A simulation does not allow such long delays. We also reduced the time in the VR environment to lower the risk of cybersickness. Cybersickness is not found in the real environment and, therefore, eliciting these symptoms would have reduced rather than increased the ecological validity of our task. Thus, there were some differences with real-life shopping, but our goal was to keep a balance between feasibility and real-life resemblance. Virtual reality remains a tool and, while VR scenarios mimic those found in real life, we cannot claim that they are entirely akin to real-life conditions. However, different components were included to increase the similarity between the VR task and real-world situations, for instance including background conversations, providing complete immersion, and having individuals physically walk in the VR environment to retrieve their items. Altogether, these characteristics helped increase the similarity with real-world contexts, even if not totally similar to everyday life situations, and represent assets compared to other, less-elaborated protocols which rely on flat screens, joystick navigation, or passive exploration. Another limitation is that the same sample was used for the two parts of the study. Hence, the possibility remains that performance in the VR task might have influenced the participants' responses on the motivation and/or presence questionnaire. However, as older adults showed lower performance than younger ones but higher motivation and an equivalent sense of presence, it does not seem to be the case. We did not include measures of exposure to video games and technology, cognitive training, or use of cognitive games, and we did not measure test-retest reliability and comparability of parallel version. Finally, the sample size for the group of younger adults was small, which might have reduced statistical power, particularly for correlations.

In conclusion, our results indicate that the use of a fully immersive Virtual Shop task is feasible in older adults: it elicits presence, is engaging, and provokes limited symptoms of cybersickness within the conditions that were used here. Furthermore, it has appropriate construct validity to measure episodic memory: performance in the VR task is positively related with performance on a traditional memory task and is sensitive to age-related differences. The finding that the VR task is a feasible, valid, and sensitive measure of memory makes it a promising tool to contribute to the clinicians' knowledge regarding an individual's daily functioning and the impact that memory impairment may have on his/her daily life. Thus, VR memory tasks could become useful instruments to reflect real-life memory and provide complementary information relative to more traditional measures. VR tasks might also contribute to enriching cognitive interventions with environments that are realistic and engaging, thus addressing some of the challenges encountered in geriatric rehabilitation, such as lack of motivation and engagement, for instance (Choi & Twamley, 2013). Finally, given that VR is feasible and that VR-based tasks are valid measures, relying on the technology to devise real-life tasks represents an interesting avenue to assess whether interventions or rehabilitation strategies provided in clinical contexts generalise to more complex environments of daily life (for illustrations see Bier, Ouellet, & Belleville, in press; Zelinski, 2009).

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References

Adamovich, S. V., Merians, A. S., Boian, R., Tremaine, M., Burdea, G. S., Recce, M., & Poizner, H. (2004). A virtual reality based exercise system for hand rehabilitation post-stroke: Transfer to function. *In Engineering in Medicine and Biology Society, 2004. IEMBS'04. 26th Annual International Conference of the IEEE* (Vol. 2, pp. 4936–4939). IEEE.

Anderson, N. D., Craik, F. I., & Naveh-Benjamin, M. (1998). The attentional demands of encoding and retrieval in younger and older adults: Evidence from divided attention costs. *Psychology and Aging, 13*(3), 405–423.

Armstrong, C. M., Reger, G. M., Edwards, J., Rizzo, A. A., Courtney, C. G., & Parsons, T. D. (2013). Validity of the virtual reality stroop task (VRST) in active duty military. *Journal of Clinical and Experimental Neuropsychology, 35*(2), 113–123. doi:10.1080/13803395.2012.740002

Arns, L. L., & Cerney, M. M. (2005). The relationship between age and incidence of cybersickness among immersive environment users. I*EEE Proceedings. VR 2005. Virtual Reality, 2005*, 267–268. doi:10.1109/VR. 2005.1492788

Bailey, J. H., & Witmer, B. G. (1994). Learning and transfer of spatial knowledge in a virtual environment. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 38*(18), 1158–1162. doi:10. 1177/154193129403801803

Bastin, C., & Van der Linden, M. (2003). The contribution of recollection and familiarity to recognition memory: A study of the effects of test format and aging. *Neuropsychology, 17*(1), 14–24. doi:10.1037/0894-4105.17.1.14

Belleville, S., Chatelois, J., Fontaine, F., Peretz, I., Renaseau-Leclerc, C., & Van der Linden, M. (2002). Mémoria: Batterie informatisée d'évaluation de la mémoire pour Mac et PC. Montréal: Institut universitaire de gériatrie de Montréal.

Benoit, M., Guerchouche, R., Petit, P.-D., Chapoulie, E., Manera, V., Chaurasia, G., & Robert, P. (2015). Is it possible to use highly realistic virtual reality in the elderly? A feasibility study with image-based rendering. *Neuropsychiatric Disease and Treatment, 11*, 557–563. doi:10.2147/NDT.S73179

Bier, B., Ouellet, É., & Belleville, S. (under press). Computerized attentional training and transfer with virtual reality: Effect of age and training type. *Neuropsychology*.

Bouchard, S., Robillard, G., & Renaud, P. (2007). Revising the factor structure of the simulator sickness questionnaire. *Annual Review of CyberTherapy and Telemedicine, 5*, 128–137.

Bowman, D. (1996). Conceptual design space-Beyond walkthrough to immersive design. In D. Bertol (Ed.), *Designing Digital Space* (pp. 225–236). New York, NY: Wiley.

Chalfonte, B. L. (1996). Spatial location memory in amnesia: Binding item and location information under incidental and intentional encoding conditions. *Memory (Hove, England), 4*(6), 591–614. doi:10.1080/ 741940998

Chaytor, N., & Schmitter-Edgecombe, M. (2003). The ecological validity of neuropsychological tests: A review of the literature on everyday cognitive skills. *Neuropsychology Review, 13*(4), 181–197. doi:10.1023/B:NERV.0000009483.91468.fb

Choi, J., & Twamley, E. W. (2013). Cognitive rehabilitation therapies for Alzheimer's disease: A review of methods to improve treatment engagement and self-efficacy. *Neuropsychology Reviews, 23*(1), 48–62.

Cronbach, L. J., & Meehl, P. E. (1955). Construct validity in psychological tests. *Psychological Bulletin, 52*(4), 281–302. doi:10.1037/h0040957

Csikszentmihalyi, M. (2000). *Beyond boredom and anxiety*. San Francisco: Jossey-Bass.

Dodson, C. S., Bawa, S., & Krueger, L. E. (2007). Aging, metamemory, and high-confidence errors: A mis-recollection account. *Psychology and Aging, 22*(1), 122–133. doi:10.1037/0882-7974.22.1.122

Farias, S. T., Harrell, E., Neumann, C., & Houtz, A. (2003). The relationship between neuropsychological performance and daily functioning in individuals with Alzheimer's disease: Ecological validity of neuropsychological tests. *Archives of Clinical Neuropsychology, 18*(6), 655–672. doi:10.1016/S0887-6177(02)00159-2

Fuchs, P., Moreau, G., & Berthoz, A. (2006). *Le traité de la réalité virtuelle volume 1: L'Homme et l'environnement virtuel*. Paris : Presse des Mines.

Henry, M., Joyal, C. C., & Nolin, P. (2012). Development and initial assessment of a new paradigm for assessing cognitive and motor inhibition: The bimodal virtual-reality stroop. *Journal of Neuroscience Methods, 210*(2), 125–131. doi:10.1016/j.jneumeth.2012.07.025

Hess, T. M. (1994). Social cognition in adulthood: Aging-related changes in knowledge and processing mechanisms. *Developmental Review, 14*(4), 373–412. doi:10.1006/drev.1994.1015

Hess, T. M., Germain, C. M., Swaim, E. L., & Osowski, N. L. (2009). Aging and selective engagement: The moderating impact of motivation on older adults' resource utilization. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, *64B*(4), 447–456. doi:10.1093/geronb/gbp020

Hess, T. M., Popham, L. E., Emery, L., & Elliott, T. (2012). Mood, motivation, and misinformation: Aging and affective state influences on memory. *Aging, Neuropsychology, and Cognition, 19*(1–2), 13–34. doi:10.1080/13825585.2011.622740

Huh, T. J., Kramer, J. H., Gazzaley, A., & Delis, D. C. (2006). Response bias and aging on a recognition memory task. *Journal of the International Neuropsychological Society, 12*(1), 1–7. doi:10.1017/S1355617706060024

Hultsch, D. F., & MacDonald, W. S. (2004). Intraindividual variability in performance as a theoretical window onto cognitive aging. In R. A. Dixon, L. Bäckman, & L.-G. Nilsson (Eds.), *New frontiers in cognitive aging* (pp. 65–68).

Hultsch, D. F., Strauss, E., Hunter, M. A., MacDonald, S. W. (2008). Intraindividual variability, cognition, and aging. In F. I. Craik, F. I. & T. A. Salthouse (Eds.), *The handbook of aging and cognition* (3rd ed., pp. 491– 556). New York, NY: Psychology Press.

Jaeger, B. K., & Mourant, R. R. (2001). Comparison of simulator sickness using static and dynamic walking simulators. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 45*(27), 1896–1900. doi:10.1177/154193120104502709

Jebara, N., Orriols, E., Zaoui, M., Berthoz, A., & Piolino, P. (2014). Effects of enactment in episodic memory: A pilot virtual reality study with young and elderly adults. *Frontiers in Aging Neuroscience, 6,* 314. doi:10.3389/fnagi.2014.00338

Johnson, M. K. (1996). Feature memory and binding in young and older adults. *Memory & Cognition, 24*(4), 403–416. doi:10.3758/BF03200930

Kennedy, R. S., Lane, N. E., Berbaum, K. S., & Lilienthal, M. G. (1993). Simulator sickness questionnaire: An enhanced method for quantifying simulator sickness. *The International Journal of Aviation Psychology, 3*(3), 203–220. doi:10.1207/s15327108ijap0303_3

Klasen, M., Weber, R., Kircher, T. T., Mathiak, K. A., & Mathiak, K. (2012). Neural contributions to flow experience during video game playing. *Social Cognitive and Affective Neuroscience, 7*(4), 485–495. doi:10. 1093/scan/nsr021

Lehmann, K. S., Ritz, J. P., Maass, H., Çakmak, H. K., Kuehnapfel, U. G., Germer, C. T., & Buhr, H. J. (2005). A prospective randomized study to test the transfer of basic psychomotor skills from virtual reality to physical reality in a comparable training setting. *Annals of Surgery, 241*(3), 442–449.

Li, K. Z., Lindenberger, U., Freund, A. M., & Baltes, P. B. (2001). Walking while memorizing: Age-related differences in compensatory behavior. *Psychological Science, 12*(3), 230–237. doi:10.1111/1467-9280.00341

Liu, L., Watson, B., & Miyazaki, M. (1999). VR for the elderly: Quantitative and qualitative differences in performance with a driving simulator. *CyberPsychology & Behavior, 2*(6), 567–576. doi:10.1089/cpb.1999.2. 567

Manera, V., Chapoulie, E., Bourgeois, J., Guerchouche, R., David, R., Ondrej, J., & Robert, P. (2016). A feasibility study with image-based rendered virtual reality in patients with mild cognitive impairment and dementia. *PloS one, 11*(3), e0151487. doi:10.1371/journal.pone.0151487

Manera, V., Petit, P.-D., Derreumaux, A., Orvieto, I., Romagnoli, M., Lyttle, G., . . . Robert, P. H. (2015). "Kitchen and cooking", a serious game for mild cognitive impairment and Alzheimer's disease: A pilot study. *Frontiers in Aging Neurosciences, 7*(24), doi:10.3389/fnagi201500024 PMID: 25852542

Miller, G. A., & Chapman, J. P. (2001). Misunderstanding analysis of covariance. *Journal of Abnormal Psychology, 110*(1), 40–48. doi:10.1037/0021-843X.110.1.40

Nash, E. B., Edwards, G. W., Thompson, J. A., & Barfield, W. (2000). A review of presence and performance in virtual environments. *International Journal of Human-Computer Interaction, 12*(1), 1–41. doi:10.1207/S15327590IJHC1201_1

Nasreddine, Z. S., Phillips, N. A., Bédirian, V., Charbonneau, S., Whitehead, V., Collin, I., & Chertkow, H. (2005). The Montreal cognitive assessment, MoCA: A brief screening tool for mild cognitive impairment. *Journal of the American Geriatrics Society, 53*(4), 695–699. doi:10.1111/j.1532-5415.2005.53221.x

Naveh-Benjamin, M. (1990). Coding of temporal order information: An automatic process? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 16*(1), 117–126. doi:10.1037/0278-7393.16.1.117

Naveh-Benjamin, M. (2000). Adult Age differences in memory performance: Tests of an associative deficit hypothesis. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 26*(5), 1170–1187. doi:10.1037/0278-7393.26.5.1170

Ouellet, É, Boller, B., Corriveau-Lecavalier, N., Cloutier, S., & Belleville, S. (2018). The Virtual Shop: A new immersive virtual reality environment and scenario for the assessment of episodic memory. *Journal of Neurosciences Methods, 303*, 126–135.

Parsons, T. D., & Courtney, C. G. (2014). An initial validation of the virtual reality paced auditory serial addition test in a college sample. *Journal of Neuroscience Methods, 222,* 15–23. doi:10.1016/j. jneumeth.2013.10.006

Parsons, T. D., & Rizzo, A. A. (2008). Initial validation of a virtual environment for assessment of memory functioning: Virtual reality cognitive performance assessment test. *CyberPsychology & Behavior, 11*(1), 17–25. doi:10.1089/cpb.2007.9934

Piolino, P., Desgranges, B., & Eustache, F. (2009). Episodic autobiographical memories over the course of time: Cognitive, neuropsychological and neuroimaging findings. *Neuropsychologia, 47*(11), 2314–2329. doi:10.1016/j.neuropsychologia.2009.01.020

Plancher, G., Nicolas, S., & Piolino, P. (2008). Apport de la réalité virtuelle en neuropsychologie de la mémoire: étude dans le vieillissement. *Psychologie & NeuroPsychiatrie du Vieillissement, 6*(1), 7–22. doi:10.1684/pnv.2008.0119

Rizzo, A., Schulteis, M., Kerns, K., & Mateer, C. (2004). Analysis of assets for virtual reality applications in neuropsychology. *Neuropsychological Rehabilitation, 14*(1–2), 207–239. doi:10.1080/ 09602010343000183

Robillard, G., Bouchard, S., Renaud, P., & Cournoyer, L. (2002). *Validation canadienne française de deux mesures importantes en réalité virtuelle : l'immersive tendencies questionnaire et le presence questionnaire*. Communication presented at the 25e congrès annuel de la Société Québécoise pour la Recherche en Psychologie (SQRP), Trois-Rivières.

Sauzéon, H., N'Kaoua, B., Pala, P. A., Taillade, M., Auriacombe, S., & Guitton, P. (2016b). Everyday-like memory for objects in ageing and Alzheimer's disease assessed in a visually complex environment: The role of executive functioning and episodic memory. *Journal of Neuropsychology*, *10*, 33–58. doi:10.1111/jnp.12055

Sbordonne, R., & Long, C. (1996). *The ecological validity of neuropsychological tests*. Orlando, FL: Deutch.

Schultheis, M. T., Himelstein, J., & Rizzo, A. A. (2002). Virtual reality and neuropsychology: Upgrading the current tools. *The Journal of Head Trauma Rehabilitation*, 17(5), 378–394.

Selwynn, N. (2004). The information aged: A qualitative study of older adult's use of information and communications technology. *Journal of Aging Studies, 18*(4), 369–384. doi:10.1016/j.jaging.2004.06.008

Shuchat, J., Ouellet, É., Moffat, N., & Belleville, S. (2012). Opportunities for virtual reality in cognitive training with persons with mild cognitive impairment or Alzheimer's disease. *Non-Pharmacological Therapies in Dementia, 3*(1), 35–54.

Slater, M., & Wilbur, S. (1997). A framework for immersive virtual environments (FIVE): Speculations on the role of presence in virtual environments. *Presence: Teleoperators and Virtual Environments, 6*(6), 603–616. doi:10.1162/pres.1997.6.6.603

Slobounov, S. M., Ray, W., Johnson, B., Slobounov, E., & Newell, K. M. (2015). Modulation of cortical activity in 2D versus 3D virtual reality environments: An EEG study. *International Journal of Psychophysiology, 95*(3), 254–260. doi:10.1016/j.ijpsycho.2014.11.003

Stevens, J. A., & Kincaid, J. P. (2015). The relationship between presence and performance in virtual simulation training. *Open Journal of Modelling and Simulation, 3*, 41–48. doi:10.4236/ojmsi.2015.32005

Sveistrup, H. (2004). Motor rehabilitation using virtual reality. *Journal of Neuroengineering and Rehabilitation*, 1(1), 10, 1–8. doi:10.1186/1743-0003-1-10

Van der Linden, M., Coyette, F., Poitrenaud, J., Kalafat, M., Calacis, F., Wyns, C., . . . et les membres du GREMEM (2004). L'épreuve de rappel libre/rappel indicé à 16 items (RL/RI-16). In M. Van der Liden, S. Adam, A. Agniel, C. Baisset Mouly, et al. (Eds.), *L'évaluation des troubles de la mémoire : Présentation de quatre tests de mémoire épisodique (avec leur étalonnage)*. Marseille, France : Solal.

Weber, R., Tamborini, R., Westcott-Baker, A., & Kantor, B. (2009). Theorizing flow and media enjoyment as cognitive synchronization of attentional and reward networks. *Communication Theory, 19*(4), 397–422. doi:10.1111/j.1468-2885.2009.01352.x

Witmer, B. G., & Singer, M. F. (1994). *Measuring presence in virtual environments* (No. ARI-TR-1014). Alexandria, VA: Army research institute for the behavioral and social sciences.

Witmer, B. G., & Singer, M. J. (1998). Measuring presence in virtual environments: A presence questionnaire. *Presence: Teleoperators and Virtual Environments, 7*(3), 225–240. doi:10.1162/105474698565686

Zelinski, E. M. (2009). Far transfer in cognitive training of older adults. *Restorative Neurology and Neuroscience*, *27*(5), 455–471. doi:10.3233/RNN–2009–0495

Annexe IV : Article 6

Computerized attentional training and transfer with virtual reality: Effect of age and training type

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Abstract

Objective: The aims of this study were to assess whether computerized attentional training improves dual-tasking abilities in older adults and whether its effect and transfer are modulated by age and the type of training provided. This study also used virtual reality (VR) as a proxy to measure transfer in a real life related context. **Method:** Sixty participants (30 older and 30 younger adults) were randomized to either: (a) single-task training (two tasks practiced in focused attention; visual detection and alphanumeric equation task); or (b) divided attention variable-priority training (varying the amount of attention to put on each task when performed concurrently). Training effects were assessed at pre- and post-training with tasks similar to the one used in training. Transfer was measured with the *Virtual car ride*, an immersive dual-task scenario and a self-reported questionnaire. **Results:** In older adults, variable-priority improved attentional control abilities and led to better transfer in the VR dual-task scenario compared with single-task. Younger adults benefited equally from the two types of training and transfer was found on the Alpha span task when performed concurrently in VR. Single-task improved the ability of all participants to carry out the tasks in the focused attention condition. No transfer effects were found on the self-reported measure for either training type or age. **Conclusion:** Attention remains plastic in old age and programs designed to improve attentional control might be beneficial to older adults. Importantly, training can produce transfer to more real life related tasks and transfer remains possible throughout the life span.

General Scientific Summary

This study shows the importance of selecting the appropriate training program on the basis of (a) what we want to improve and (b) the population to which it is addressed. Indeed, older adults were found to benefit to a larger extent than younger adults from a training targeting attentional control abilities (for which difficulties were found prior to training), and that this training gain may transfer to tasks of everyday life.

Keywords: dual-task, cognitive training, transfer, virtual-reality, aging.

A range of different cognitive training programs can lead to training-specific improvements in older adults (Anguera et al., 2013; Ball et al., 2002; Karbach & Schubert, 2013; Lövdén, Bäckman, Lindenberger, Schaefer, & Schmiedek, 2010; Lustig, Shah, Seidler, & Reuter-Lorenz, 2009). However, it is critical to identify whether the benefit resulting from cognitive training transfers beyond the trained tasks to the daily lives of older adults, and whether different training types result in different effects and transfer (Melby-Lervåg & Hulme, 2013; Noack, Lövdén, Schmiedek, & Lindenberger, 2009; Owen et al., 2010). In this study, our aims are to: (a) assess whether computerized attentional training improves dual-tasking abilities in older adults and whether the effect transfers to tasks similar to those encountered in daily life, (b) examine whether effect and transfer are of the same magnitude in older and younger adults, (c) unveil training aspects that modulate transfer effects and, in particular, whether divided attention training yields a larger transfer than repeated practice and, (d) use transfer tasks that reflect real life situations, as most studies measure transfer with self-reported questionnaires or tasks that lack in ecological validity. The background relevant to these objectives is briefly presented below.

Impact of Attentional Training on Proximal Outcomes

Attentional control is defined as a top-down executive process that enables the execution of complex goal-oriented behaviors under attentionally demanding conditions, such as a complex dual-tasking paradigm (Milham et al., 2002). It is particularly important in situations with a strong competition for response selection and is considered a critical component for successful performance in a wide variety of complex cognitive tasks. Models of attentional control have emphasized the role of goal maintenance in attentional control abilities. In dual task conditions, goal maintenance is involved when there is a strong competition for response selection between the two tasks or when one of the two tasks has to be prioritized (Braver et al., 2001; Braver & West, 2008). There is now increasing evidence that training attentional control can improve dual-task performance and the control of attention when assessed with proximal measures, that is, with tasks that are close to those used during training.

Different types of attentional training show differences in their level of efficacy, which may be indicative of the active ingredient responsible for the improvement. In particular, many studies have reported the benefits of variable priority training in reducing dual-task cost (Bier, de Boysson, & Belleville, 2014; Kramer, Larish, & Strayer, 1995; Lussier, Bugaiska, & Bherer, 2016) and improving younger (Gopher, 2007; Gopher, Weil, & Bareket, 1994; Gopher, Weil, & Siegel, 1989) and older adults' ability to control attention in response to external demands (Bier et al., 2014; Lee et al., 2012; Lussier et al., 2016; Voss et al., 2012; Zendel, de Boysson, Mellah, Démonet, & Belleville, 2016). In variable priority training, participants complete two tasks in combination, but are instructed to vary the attentional priority that they place on the two tasks. It is hypothesized that variable priority training improves one's ability to purposely control attentional locus and increases metacognition (Gagnon & Belleville, 2012). Including variable priority in attentional training programs appears critical in improving dual tasking. Recent studies from our laboratory found larger dual-task coordination gain in older adults following variable priority training compared with (a) a fixed priority training (where participants are asked to allocate the same amount of attention on each task performed concurrently); and (b) a single task training (where participants were trained to practice each task individually in focused attention; Bier et al., 2014; Gagnon & Belleville, 2012; Zendel et al., 2016). A few studies have compared the effect of variable training in older and younger adults, to determine whether older adults show similar benefits from variable-priority training as younger ones when measured with proximal measures. Some studies show equivalent improvement in the two age groups (Bherer et al., 2005, 2008), and at least one study reported that older adults benefit more from variable priority training than younger adults (Kramer et al., 1995). There is thus evidence that this type of training might be particularly well suited to older adults when the effect is assessed with proximal measures.

Impact of Attentional Training on Transfer

Because variable priority training involves metacognitive abilities and relies on flexible decisions based on environmental demands, one might expect it to result in transfer effects (Belleville, Mellah, de Boysson, Demonet, & Bier, 2014; Gopher, 2007; Lussier et al., 2016). Gopher (2007) has indeed suggested that variable priority training increases the participant's sensitivity and ability to cope with dynamic changes in demand and is likely to facilitate the coping and transfer of the acquired skill components to new tasks or conditions. Training transfer is defined as the aptitude for training to engage improvement on cognitive abilities or tasks that are not those that were trained (content transfer; Butterfield & Nelson, 1991; Noack et al., 2009) or to allow a successfully learned skill, behavior or strategy to be applied in a context that is different from the one where it was learned (context transfer; Barnett & Ceci, 2002; Bransford, Brown, & Cocking, 2000; Lobato, 2006; Perkins & Salomon, 1988; 1992).

A few studies have reported content transfer from variable priority training in older adults. In a study conducted by Kramer, Larish, and Strayer (1995), variable priority training improved the performance of older adults on the trained task (monitoring and changing display while responding to alphabet arithmetic items) and on a novel dual-task paradigm involving simultaneous scheduling tasks and a paired associate running memory tasks. Transfer on the new task was greater for the variable priority compared to the fixed priority training group. Similarly, Lussier, Bugaiska, and Bherer (2016) found a larger dual-task cost reduction for the variable priority compared with the fixed priority training group on transfer tasks, which changed the nature of the stimuli (e.g., letters vs. numbers) while keeping the same input of presentation (e.g., visual vs. auditory), and on tasks changing both the nature of the stimuli and the input of presentation. A few studies, however, did not observe the advantage of variable priority training over fixed priority training on content transfer measures (Bherer et al., 2005) or found no transfer effects for either training type (Bherer et al., 2008).

Whether age impedes training transfer is unclear. Some have hypothesized that the reduced neural plasticity associated with aging would limit the ability for older adults to benefit from transfer effects (Dahlin, Neely, Larsson, Bäckman, & Nyberg, 2008; Kühn & Lindenberger, 2016). In line with this hypothesis, some studies have found smaller content transfer in older adults compared to their younger counterparts (Dahlin et al., 2008; Derwinger, Neely, Persson, Hill, & Bäckman, 2003; Neely & Backman, 1993). However, age-equivalent transfer supporting preserved cognitive plasticity in advanced age was also reported (Bherer et al., 2005; Karbach & Schubert, 2013; Lussier, Gagnon, & Bherer, 2012). Interestingly, studies reporting unimpaired transfer relied on variable priority training. It is thus possible that this training condition is most appropriate to induce transfer in older adults as suggested by Gopher (2007).

Measuring Transfer in Everyday Situations

Overall, many studies have shown that divided attention variable priority training can yield transfer (Bherer et al., 2005; Kramer et al., 1995; Lussier et al., 2016; Lussier et al., 2012). However, these studies most often measure content transfer that is, transfer measured with cognitive tasks that are close to the training modalities. Such transfer measures are very far from representing the complexities of the tasks encountered in everyday situations, which makes it difficult to interpret the potential positive impact of divided attention variable priority training on a participant's everyday life. Furthermore, a few studies reported little transfer when transfer tasks differed from training on more than a few dimensions. This suggests that training may not transfer easily to real life situations, as they are typically very different from the training content and format. This stresses the importance of measuring context transfer, and whether training transfers to situations from everyday life.

Positive effects of cognitive interventions on self-reported questionnaires targeting activities of daily living (ADL) have been found in healthy older adults (Rebok et al., 2014; Willis et al., 2006) and in individuals with mild cognitive impairment (for a review see Chandler, Parks, Marsiske, Rotblatt, & Smith, 2016). For example, in the active study, where participants were trained on one of three cognitive interventions (memory, reasoning, or visual attention), transfer was measured using functional outcomes such as a self-reported questionnaire measuring the participants' difficulty in performing ADL tasks. The attentional training, which focused on visual search and the ability to identify and locate visual information quickly in a divided attention format, was found to improve proximal cognitive outcomes and resulted in a reduced decline in self-reported IADL function at a 10-year follow-up compared with memory training (Rebok et al., 2014). Gagnon and Belleville (2012) compared transfer resulting from variable priority and fixed priority training in persons with mild cognitive impairment (MCI) with a self-reported questionnaire (Divided Attention Questionnaire [DAQ]) designed to provide a subjective account of the participant's difficulties in everyday activities that require divided attention (e.g., talking to someone while cooking or driving; listening to music on the radio while doing paperwork). Unexpectedly, the two training conditions were associated with a higher level of complaint on the DAQ after training. This could be due to the fact that participants were more aware of the difficulties they could have experienced in their daily lives after training. This illustrates the challenges related to the subjective nature and use of self-reported measures and raises concerns about participants lacking insight into beneficial changes produced by the training (Stuss et al., 2007; Zanardo, De Beni, & Moè, 2006).

Only a few studies have attempted to use performance-based tasks that bridge between the lab and home environments. For instance, Gopher, Weil, and Bareket (1994) found transfer from a 10-hr training variable priority training program to actual flight tasks in a group of young cadets. The authors found that the participants' flight performance increased by 30% after training on a complex computer game (Space Fortress). In the training, participants were asked to control the movement of a spaceship while firing missiles to destroy a space fortress. The variable priority component required participants to vary their focus of attention on different aspects of the game. A similar training involving attention management was also found to improve pilots' abilities to cope with very high workloads and competing attentional demands that are typical in flight training (Hart & Battiste, 1992). Boot et al. (2010) also showed a transfer effect following variable priority training on a complex simulated real world task (radar monitoring and flight simulator) in younger adults. Thus, variable priority training results in enhanced dual-task performance on complex real-world tasks. However, more research is needed to confirm that a variable priority training program produces more transfer than single-task training. We also need to know whether older and younger adults show similar transfer to complex tasks, as most studies focused on younger populations.

Virtual-Reality: A Tool to Measure Transfer Effect

Virtual reality (VR) may be a promising addition to a toolkit designed to assess the impact of cognitive training in real life settings. It is a computer-based technology that allows users to interact in real time with a multisensory simulated environment via behavioral interfaces (Saposnik et al., 2016). Its potential lies in its capacity to reproduce situations close to daily life while providing a controlled, standardized, and safe environment (Rizzo, Schultheis, Kerns, & Mateer, 2004). VR appears to provide valid measures of real world capacities. A few studies reported that participants' performances in virtual environments are closely related to those in real word environments, and that this is the case in both younger (Waller, Hunt, & Knapp, 1998) and older adults (Allain et al., 2014; Cushman, Stein, & Duffy, 2008; Plancher, Gyselinck, Nicolas, & Piolino, 2010). For example, Cushman, Stein, and Duffy (2008) found correlations between navigational deficits measured in the lobby of the Strong Memorial Hospital and those measured in a virtual reproduction of this environment. Plancher, Gyselinck, Nicolas, and Piolino (2010) found that older adults' memory recall performance of elements seen during the exploration of a virtual city correlated with their memory complaints in daily life. VR environments also provide a *sense of presence* for the user, which is the subjective experience to be in a place when one is physically in another (Witmer & Singer, 1998). This *sense of presence* was shown to help evoke emotional responses like the ones experienced in real life situations (Schuemie, Van Der Straaten, Krijn, & Van Der Mast, 2001). Thus, the sense of presence evoked by VR and its emotional correlates contributes to making it a representative tool of everyday life activities. As VR provides well-controlled yet ecological situations, we propose to use this technique as a way to appraise impact in real word situations in addition to self-reported questionnaires. To the best of our knowledge, VR has never been used to measure transfer effects following cognitive training.

Summary and Objectives

In summary, many studies suggest that divided attention variable priority training improves attentional control capacities and dual-task performance and that the benefit is larger than the one found from pure dual-task training or repeated practice of an individual task. In the majority of studies, this advantage was shown to transfer to untrained tasks that are close to the ones used in training (e.g., the same task using a different input or output modality). However, little is known about the effect of training on tasks more akin to real life or that reflect the complexity of the processes involved in attentional tasks of everyday living. It is also unclear whether age reduces the capacity to benefit from cognitive training and to transfer that benefit to untrained tasks, as results from the literature are inconsistent. Furthermore, most studies have assessed training to real-life tasks with younger populations, which limits the conclusion with regards to the transfer in older adults. These questions will be addressed here.

We will assess the effect of two types of attentional training, variable priority training versus single-task training. In variable priority training, participants are asked to vary the amount of attention placed on each task performed concurrently (alphanumeric equation and visual detection). In single-task training, participants perform both tasks individually in focused attention. Because our focus was on transfer, we will compare variable priority training with a condition that is active, but for which we do not expect major dual task improvements based on previous findings (Bier et al., 2014; Zendel et al., 2016). Training effect will be measured with tasks that are close to the ones used in training. Transfer will be measured using a novel complex VR scenario that mimics a dual task situation that could occur while being a passenger in a car: the *Virtual car ride.* The dual-task VR scenario combines two tasks: the detection of a visual road sign (detecting a target city name passing on one of the road signs) and a complex working memory task presented orally (recalling a list of words in alphabetical order). We chose this task because it allows control over presentation and response conditions. Because working memory is known to be involved in complex real-life cognitive processes such as oral comprehension and logical reasoning, it was considered to be an appropriate compromise. Participants also complete the Cognitive Failure Questionnaire (Broadbent, Cooper, FitzGerald, & Parkes, 1982), a self-reported questionnaire where they indicate how often they judge committing errors in the completion of attention-demanding tasks from everyday life (for instance, Do you fail to hear people speaking to you when you are doing something else? *never* to *very often*). Based on previous studies (Bier et al., 2014; Zendel et al., 2016), we expect that only the variable training group will improve attentional control measured on a proximal measure. We also expect that the variable condition will yield transfer, hence reducing divided attention cost in the VR environment. Older adults should benefit as much as younger ones from variable training but whether they show equivalent transfer is unclear based on previous findings.

METHOD

Participants

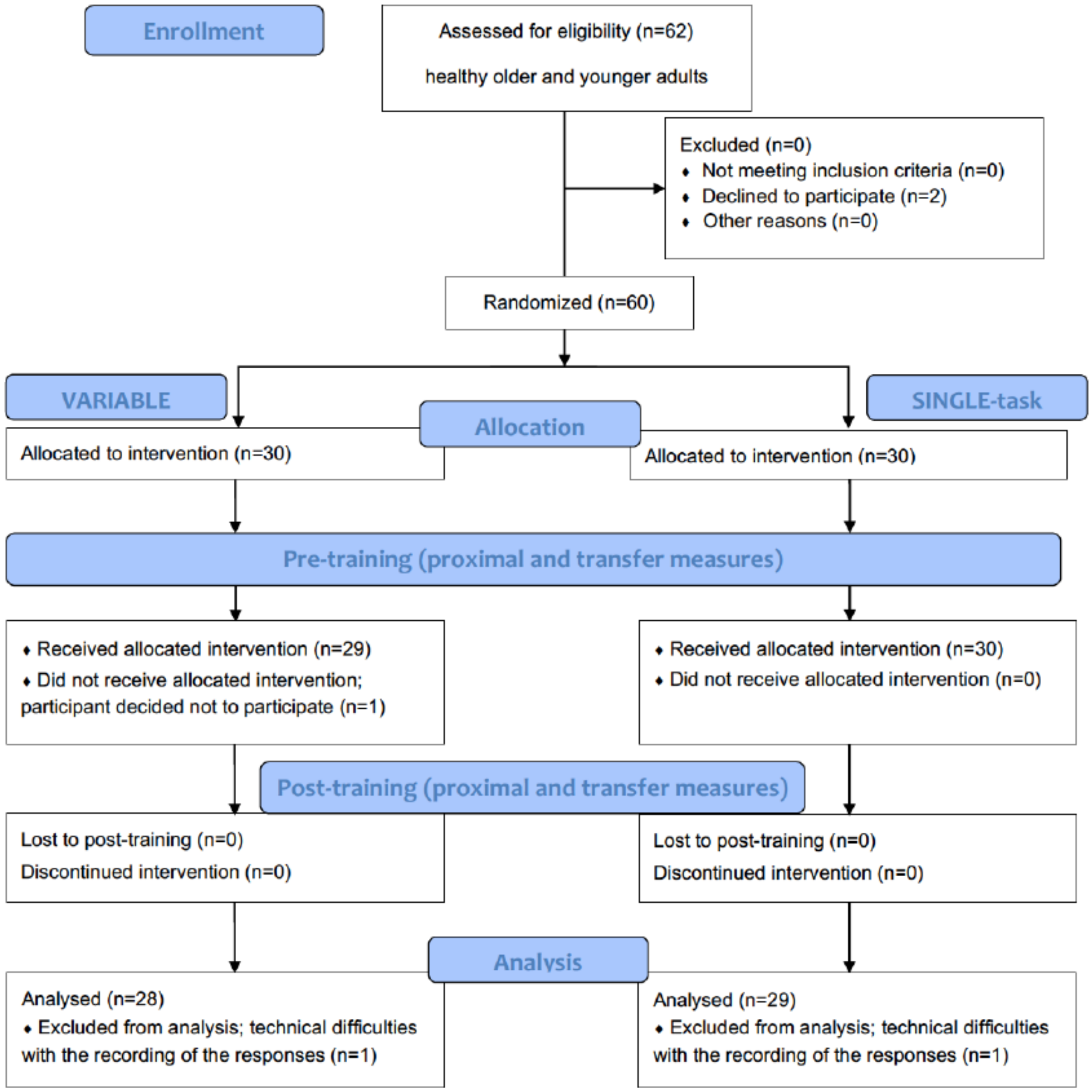
The study included 60 participants, 30 older adults and 30 younger adults. All participants were recruited in the community through advertisements in retirement centers and magazines for seniors. Participants were included if they were French-speaking and community dwelling, living in the Montreal area, right-handed, and had normal or corrected-to-normal hearing and vision. Exclusion criteria included: alcoholism or substance abuse, presence or history of a neurological disorder or stroke, presence or history of a severe psychiatric disorder (e.g., depression, schizophrenia, bipolar disorder), general anesthesia in the past 6 months, and impaired performance on the Montreal Cognitive Assessment (Nasreddine et al., 2005).

Participants underwent a telephone interview to provide initial selection information. Eligible individuals were invited to come to the laboratory for a standardized clinical and neuropsychological battery in order to evaluate their clinical status and cognitive functioning. The first session included one test of “fluid” intelligence (Wechsler, 1997) and one of “crystallized” intelligence (vocabulary subtest, WAIS-IV; Wechsler, 2008). Older participants also completed the Montreal Cognitive Assessment (MoCA; Nasreddine et al., 2005). The study was approved by the Institut universitaire de gériatrie de Montréal Human Ethics Committee. Informed written consent was obtained from all subjects according to the Declaration of Helsinki.

Design

Subject flow is shown in Figure 1 according to the CONSORT reporting instructions (Schulz, Altman, & Moher, 2010). Participants were randomly assigned by an independent research assistant to one of two training conditions, stratified by education and age to equate the groups on those variables. Proximal and transfer measures were completed in a single session one week prior to the first training session and 1 week following the last training session. Two task versions were used for the pre- and postsession (for the proximal and VR tasks), and the order of administration was counterbalanced across participants.

Figure 1. Flow chart according to the Consort reporting instructions



Training Method

The training program was similar to one used in previous studies (Belleville et al., 2014; Bier et al., 2014; Zendel et al., 2016). The divided attention paradigm included two tasks: a visual detection task and an alphanumeric equation task. The tasks vary in attentional demand, which should increase reliance on goal maintenance when required to vary attentional priority. Both tasks were run on Compaq Pentium d530 computers, and responses were provided on the keyboard. *In the alphanumeric equation task*, participants were asked to judge the accuracy of a set of visually presented alphanumeric equations. The stimuli consisted of addition or subtraction equations containing letters (from N to Z) and numbers (1 or 2) in the format x (+ or -) $n = z$. The letter x corresponded to the starting point in the alphabet, the + or - sign indicated the direction of the equation, and n was the number of letters that separated the starting point from z. For example, the equation N + 2 = P is correct because P is two letters after N in the alphabet, whereas the equation S - 1 = Q is incorrect because one letter down from S in the alphabet is R and not Q. Each equation was visually presented in the middle of the screen for a maximum period of 3750 ms with 1500-ms interstimulus intervals. The participant was asked to judge the accuracy of the equation by pressing one of two keys: the “F” key with the left index finger when the equation was incorrect, and the “J” key with the right index finger when the equation was correct. Half of the equations were correct. Incorrect ones were formed by selecting a letter that was one or two positions away from the correct result. Each training session comprised 12 blocks of 20 trials. The number of addition versus subtraction, one versus two steps, as well as correct versus incorrect equations, was equivalent across blocks of trials. *In the visual detection task*, red or white rectangles (3 x 30 square-inch (7.6 x 76 cm2) appeared randomly at the bottom of the computer screen for 500 ms each, interspaced by 250-ms intervals (ISI). Participants were asked to press the spacebar key every time the rectangle was red and were to do so as quickly and as accurately as possible. Accuracy (AC) and reaction time (RT) were recorded for both tasks. If a participant did not provide an answer within the required period of time, the next trial was presented and the previous was considered as failed. To provide a baseline, all participants completed two blocks of each task under focused attention at the beginning and end of each session.

In the variable priority training condition (VARIABLE), participants were asked to perform both tasks (alphanumeric equation and visual detection) simultaneously and to vary their allocation priority across a series of blocks. Each session comprised 12 blocks (four blocks in focused attention and eight in divided attention). Prior to each block, instructions informed the participants as to how much attention should be given to each task. There were two different levels of attentional allocation priority: 80% equation and 20% equation. The 80% equation instruction condition indicated that participants should allocate 80% of their attention to the alphanumeric equation task and 20% to the visual detection task. For the 20% equation instruction condition, 20% of the participants' attention was asked to be on the alphanumeric equation task and 80% on the visual detection task. The instructions were visually presented on the screen and read aloud to participants. To enable better understanding, instructions were supported by an illustration of a rectangular box divided into two colored parts of different proportions, each representing the percentage of attention required by each task. After each block, a histogram was presented to the participants indicating their baseline level for the training session (as measured earlier in the focused attention condition) and the expected accuracy given the emphasis instruction condition. For example, if a participant responded correctly on 75% of the alphanumeric equations in the focused attention condition, they would be expected to have 60% accuracy in the 80% equation emphasis instruction condition. Before displaying their actual performance on the histogram, participants were asked to draw their own estimate on a paper histogram. Participants were thus evaluating their own performance and informed as to whether they had attained the requested priority proportion to allow them to better adjust the emphasis at the next block.

Each equation comprised five rectangles, including one to three red rectangles. Thus, 40% of the rectangles were red, with a total of 20 to 100 rectangles per block, depending on the participant's speed. The, visual detection targets were only presented during the time participants took to solve the equation. This ensured that the participants were in a state of divided attention during the entire period.

In the single task training condition (SINGLE-task), participants were asked to practice the alphanumeric equation task and the visual detection task under focused attention, that is, without combining them. To equate the number of blocks with the VARIABLE priority training condition, participants completed six blocks for one task and seven blocks for the other task in each session. The number of blocks for each task alternated between sessions so that participants would receive the same amount of exposure to both tasks over the course of the whole training program. The starting task at session one was counter-balanced across participants.

Both training were provided in eight 1-hr sessions on weekdays over a period of 2 weeks. Each training session was performed in groups of two or three participants.

Outcomes Measure

Proximal outcome measure

The proximal outcome measures were focused and divided attention tasks. Participants were asked to perform a visual detection task and an alphanumeric equation task separately (focused attention) and in combination (divided attention). The task was similar to that used in training, except that the equations contained letters from a different part of the alphabet (A to M rather than N to Z) and no feedback was provided. Each condition (focused and divided) was presented in six blocks of eight trials (for a total of 48) following an ABA design. Participants first completed each task with focused attention, followed by two blocks of the dual-task condition (80% equation, 20% equation). The two tasks were then completed again with focused attention. No feedback was given during the task.

Transfer measures in VR

Generalization of training effects was measured with the *Virtual car ride*. The virtual environment of the *Virtual car ride* was developed and rendered using the 3DVIA Virtools 5 3D engine and was run on a Dell Precision T3600 PC with an Inter® Xeon® CPU ES-1620 0 (3.60 Ghz, 10 Gbytes in RAM) processor and a NVIDIA GeForce GTX 600 Ti graphic card. The task was designed in collaboration with *Cliniques et développement in virtuo* (www.invirtuo.com). The virtual environment was three dimensional and the immersion was produced by an Nvisor ST50 audio-visual headgear and by a Worldviz PPT-X studio tracking system that allowed the participant to rotate their head in a 360-degree view, as well as look up and down. Participants were asked to sit on a chair while the assistant installed the headgear and the hand device (computer mouse). They were then immersed in the virtual environment and told that they were free to move their head and explore the environment. Car sounds were audible in the environment and other vehicles appeared on the road as distractors and to mimic real life situations (ambulance, cars).

In the *Virtual car ride*, participants sat in the passenger's seat of a car moving on a highway. They were not asked to drive, but were asked to guide the driver to their destination in the divided (road signs detection; Alpha-Span) or focused attention condition. In the road signs detection task, the participants were instructed to help the driver with directions to go to a specific city. A fictive city name was given to them prior to the beginning of the task and varied depending on the version of the task used (Chauminont; Montformeil). Participants were asked to press the left mouse button with their left index finger each time they would see the target city name passing on one of the road signs. The *Virtual car ride* lasted 4 min and included 40 road signs, 20 of which corresponded to the target, and the other half were distractors. In the Alpha span task (Belleville, Rouleau, & Caza, 1998), participants were asked to recall a list of words in alphabetical order. As a first step (outside the VR), a classic word span procedure was used to assess their short-term memory (STM) capacity. Then, 10 individually span level adjusted sequences of words were presented to the participants who were asked to rearrange and recall the words in alphabetical order. For example, the words *orme, pain, corde* should be recalled *corde, orme, pain*.

Participants were instructed to perform both tasks (the road signs detection and the Alpha span task) concurrently in a divided attention condition and to put an equal amount of attention on each task. As soon as the car started moving, the first sequence of words to be recalled was read at a rate of one item per second and the participants had to recall the words in their alphabetical order. If a participant did not provide an answer within the required period of time, the next list was provided and the sequence was considered as failed. A total of 10 to 12 lists were provided for each participant depending on the time taken to complete the car ride. Accuracy (AC) was recorded for each of the tasks. The same procedure was used for the condition of focused attention, except that all participants received a fixed number of 10 sequences for the Alpha span task. Participants completed the Alpha span task first in focused attention, followed by the road sign detection tasks in focused attention. Both tasks were then combined in the divided attention condition.

RESULTS

Results Demographic and Clinical Data

The participants randomized to the two training conditions were first compared for demographics and clinical characteristics. ANOVAs with age, education level, and performance on clinical measures as dependent variables, and training group (VARIABLE vs. SINGLE-task) as between-groups factors, showed no significant differences between the two training groups for both younger and older adults (see Table 1).

Table 1

Demographic and Clinical Characteristics for All Participants Included in the Final Sample

	Old		Young	
	SINGLE Training (*n* = 14)	VARIABLE Training (*n* = 13)	SINGLE Training (*n* = 15)	VARIABLE Training (*n* = 15)
Age (years)	73.05 (6.36)	69.70 (5.13)	25.71 (4.21)	26.19 (4.62)
Gender	12 F, 2 H	10 F, 3 H	11 F, 3 H	12 F, 3 H
Education (years)	14.85 (4.63)	14.77 (2.68)	15.43 (2.06)	15.94 (2.12)
Moca (/30)	28.14 (1.20)	28.92 (1.38)	-	-
GDS (/15)	0.92 (1.27)	1.69 (2.01)	-	-
BDI-II	-	-	2.79 (3.56)	4.13 (2.86)
Vocabulary WAIS-IV subtest	11.50 (2.10)	12.46 (1.12)	11.86 (1.46)	11.38 (1.97)
Digit Symbol-Coding WAIS-IV subtest	14.85 (1.47)	14.15 (2.51)	13.29 (2.73)	13.88 (3.03)

Note. Means scores are presented with standard deviations in parentheses. GDS = Geriatric depression scale; BDI = Beck Depression Scale; WAIS-IV = Wechsler Adult Intelligent Scale-4th Edition.

Proximal Measures

Dependent variables

For the proximal outcome measures, we calculated a dual-task cost by combining the AC and RT for each task in the divided attention condition relative to the focused attention condition, with the following equation: {[(RT divided - RT focused)/RT focused] + [(AC focused - AC divided)/AC focused]}. In the equation, RT focused and AC focused represent performance in the focused attention condition for RT and accuracy. RT divided and AC divided represent performance in the divided attention condition (80% equation or 20% equation) for RT and accuracy. Thus, the formula controls for baseline performance. This divided attention cost represents the proportional loss of performance in the divided attention condition as a function of performance in focused attention and was used as the dependent variable.

Pre-training effects

To assess whether there were age differences in the ability to control attention prior to training and to assess whether the training groups were equivalent, performance in the pre-training session was first analyzed using a mixed ANOVA with dual-task cost as a dependent variable, emphasis (20% equation; 80% equation) and task (alphanumeric equation; visual detection) as within-subject factors, and training group (SINGLE- task; VARIABLE) and age (young; old) as between-subjects factors.

The ANOVA showed no main effect of training group ($F < 1$) and no interaction involving that factor, ($F < 1$), indicating that the two training groups had similar performance at baseline. A main effect of task was found $F(1, 53) = 465.95$, $p < .001$ (n2 = 0.90), as participants had an overall higher dual-task cost on visual detection ($M = 0.84$) than on alphanumeric equation ($M = 0.23$). There was also a main effect of age, $F(1, 53) = 57.51$, $p < .001$ (n2 = 0.52), as older adults had a higher dual-task cost ($M = 0.63$) compared with younger adults ($M = 0.42$). This effect was qualified by a significant Emphasis x Task x Age interaction, $F(1, 53) = 17.33$, $p < .001$ ($\eta 2 = 0.25$). Inspection of Figure 2a and 2b suggests that the interaction arises from the fact that younger adults were better able to modulate their attention between the visual detection and alphanumeric tasks according to the instructions compared to their older counterparts. To confirm this interpretation, ANOVAs were computed separately for each age group with the variables Emphasis and Task as repeated factors.

In younger adults, a main Task effect was found, $F(1, 29) = 119.46$, $p < .05$ ($\eta2 = 0.81$), indicating that the dual-task cost was higher on the visual detection task ($M = .64$) compared to the alphanumeric equation task ($M = .21$). This effect was qualified by Task x Emphasis interaction, $F(1, 29) = 101.18$, $p < .05$ ($\eta2 = 0.78$). Decomposition of the interaction revealed that for both tasks, the dual-task cost varies as a function of the emphasis instruction, but that the emphasis effect goes in the opposite direction for the two tasks. Thus, the main effect of Emphasis, $F(1, 29) = 101.18$, $p < .001$ $\eta2 = 0.67$) for the alphanumeric equation task was due to the fact that the dual-task cost was lower in the condition that requires prioritizing the alphanumeric equation task, the 80% Equation, ($M = 0.04$), relative to the one that requires prioritizing detection, the 20% Equation ($M = 0.37$) ($p < .05$). Inversely, the main effect of Emphasis, $F(1, 29) = 101.18$, $p < .001$ $\eta2 = 0.78$, for the visual detection task was significant, as the dual-task cost was lower in the 20% Equation ($M = 0.43$) than in the 80% Equation ($M = 0.84$) ($p < .001$). Interestingly, and as shown in Figure 2a, there is a larger cost for the visual detection task than the alphanumeric equation when participants are asked to prioritize the latter, but this effect is no longer present when participants are asked to prioritize visual detection (20% Equation). These results suggest that younger adults can modulate their attentional priority between both tasks as a function of the emphasis instruction.

Figure 2.

(a)

(b)

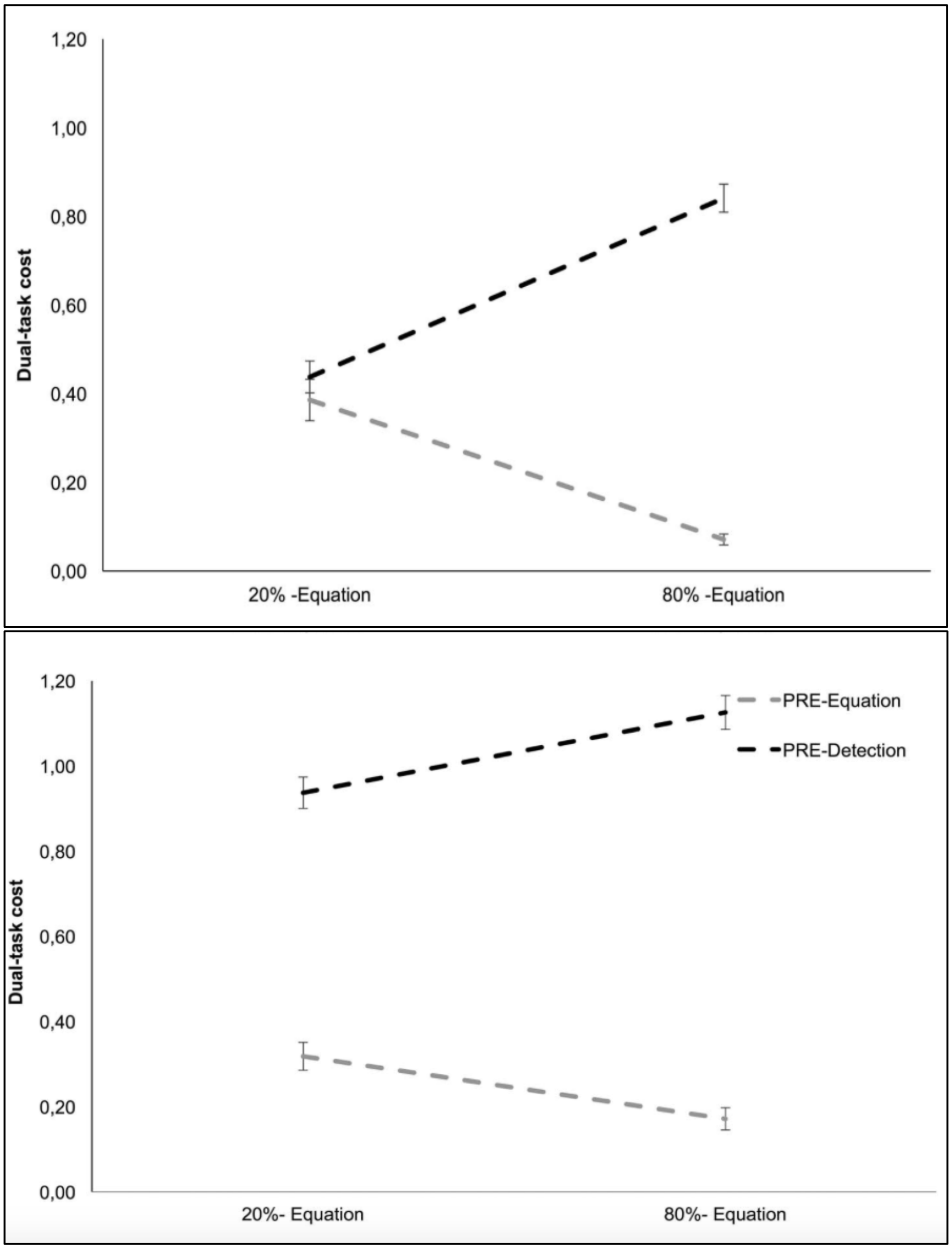


Figure 2. Divided attention cost for young (a) and older adults (b) on each task (alphanumeric equation; visual detection) as a function of emphasis instructions (20%-Equation; 80%-Equation) at baseline (error bars represent standard error).

The pattern is different in older adults. Similar to younger adults, a main effect of Task was found, $F(1, 26) = 417.83$, $p < .001$ ($\eta 2 = 0.94$), indicating a higher dual-task cost for the visual detection task ($M = 1.03$) compared to the alphanumeric equation task ($M = 0.24$), and this effect was qualified by an Emphasis x Task interaction, $F(1, 26) = 34.69$, $p < .001$ ($\eta 2 = 0.58$). Decomposition of the interaction revealed a significant Emphasis effect for both the visual detection $F(1, 26) = 34.69$, $p < .001$ $\eta 2 = 0.43$ and the alphanumeric equation tasks $F(1, 26) = 34.69$, $p < .001$ $\eta 2 = 0.50$. The Emphasis effect goes in the opposite direction. For the alphanumeric equation task, the main effect of Emphasis is explained by a lower cost in the 80% Equation emphasis condition ($M = 0.17$) than in the 20% Equation emphasis condition ($M = 0.31$), whereas for the visual detection task, it is explained by a larger cost in the 80% Equation emphasis condition ($M = 1.12$) than in the 20% Equation emphasis condition ($M = 93$). The source of the three-way interaction appears to arise from the fact that the disadvantage for dual-task cost on visual detection is more marked in older adults than in younger adults and their change in cost with emphasis is smaller. As a result, the cost disadvantage for the visual detection task is still present in older adults in the condition that requires prioritizing that task, contrary to what is found in younger adults. Thus, older adults prioritize the alphanumeric equation task, irrespectively of the emphasis conditions.

When comparing age groups on divided attention costs, older adults showed a higher visual detection dual-task cost than younger adults for both emphasis conditions (both $p < .001$, see Figure 2a and 2b), whereas they showed a larger alphanumeric equation task dual-task cost only for the 80% Equation emphasis.

Training effects on the proximal measures

Divided attention condition

To assess training effects, dual-task cost scores were analyzed with a mixed ANOVA using Time (pre- and post-training), Emphasis (80% Equation; 20% Equation), and Task (alphanumeric equation; visual detection) as within-subject factors, and Training type (SINGLE-task; VARIABLE) and Age (young; old) as between-subject factors. The Time x Emphasis x Task xTraining type x Age interaction was significant, $F(1, 53) = 3.26$, $p < .001$ ($\eta 2 = 0.16$). Inspection of Figures 3a, 3b and 3c indicate that this is due to training conditions having different effects in younger and older adults. To allow interpretation of the interaction, ANOVAs were computed separately for older and younger adults with the variables Time, Emphasis, Task, and Training type.

For younger adults, the analysis revealed no main effect of Training type ($F < 1$) and no interaction involving that factor. As the two training types led to similar outcomes, Figure 3a shows pooled dual-task cost. Importantly, younger adults showed a significant Time x Task interaction, $F(1, 28) = 53.49$, $p < .001$ ($\eta 2 = 0.66$). This was a cross-over interaction as shown in Figure 3a as the dual-task cost was modified on both tasks following training, but in the opposite direction. The visual detection dual-task cost was reduced from pre- ($M = 0.64$) to post-training ($M = 0.46$), whereas the alphanumeric equation dual-task cost increased from pre- ($M = 0.21$) to post-training ($M = 0.39$) ($p < .001$ & $p < .001$, respectively). As a result, the dual-task cost, which was larger for visual detection than for alphanumeric equation prior to training, was no longer different after training. Consistent with the results presented in the section on pre-training, this analysis also revealed a Task x Emphasis interaction, $F(1, 28) = 96.69$, $p < .001$ ($\eta 2 = 0.78$) indicating that the dual-task cost for the two tasks varies as a function of the emphasis instruction condition (p < .001). None of the other interactions reached significance. These results show that both training modified younger adults' initial bias in favor of the alphanumeric equation task, resulting in a reduction of the dual-task cost on visual detection and an increase of dual-task cost on the alphanumeric equation task.

For older adults, a significant Time x Emphasis x Task x Training type interaction, $F(1, 25) = 4.28$, $p < .05$, ($\eta 2 = 0.15$), was found. Inspection of Figures 3b and 3c suggests that this is due to the fact that only the participants trained in VARIABLE priority training improved their ability to modulate their attention according to the instruction after training. To support this intepretation, we computed Time x Emphasis x Task ANOVAs separately for the VARIABLE and SINGLE-task training types condition, which revealed that the two conditions led to different training effects.

In the VARIABLE condition, we found a significant Emphasis x Time x Task interaction, $F(1, 12) = 6.41$, $p < .05$, ($\eta 2 = 0.35$). No Time effect was found on the alphanumeric equation task on either emphasis condition ($F < 1$, in both cases). There was a

Time effect in both emphasis conditions for the visual detection task. The interaction seems to arise from a larger emphasis effect following training than prior to training, and a larger training-related dual-task cost reduction on the visual detection task when the condition required prioritizing that task (20% Equation) than when it required prioritizing the Equation task (M = 0.90 vs. 0.54). Considering older adults had more difficulty prioritizing the visual detection task prior to training when asked to do so (20% Equation condition), this indicates that after training, participants in the VARIABLE training group were able to modify their attentional priority in dual-tasking as a function of task instructions.

In SINGLE-task training, there was no effect of Time and none of the interactions involving Time were significant (Figure 3c). Thus, older adults in the SINGLE-task training condition did not improve their dual-task cost or improve their ability to vary their level of attention based on instructions. Of note is the fact that the group showed an Emphasis x Task interaction, $F(1, 13) = 15.56$, $p < .05$ ($\eta 2 = 0.54$) due to the fact that in the visual detection task, participants had a lower dual-task cost in the 20% Equation (M = 0.91) than in the 80% Equation emphasis instruction condition (M = 1.09) (p = .001).

Figure 3.

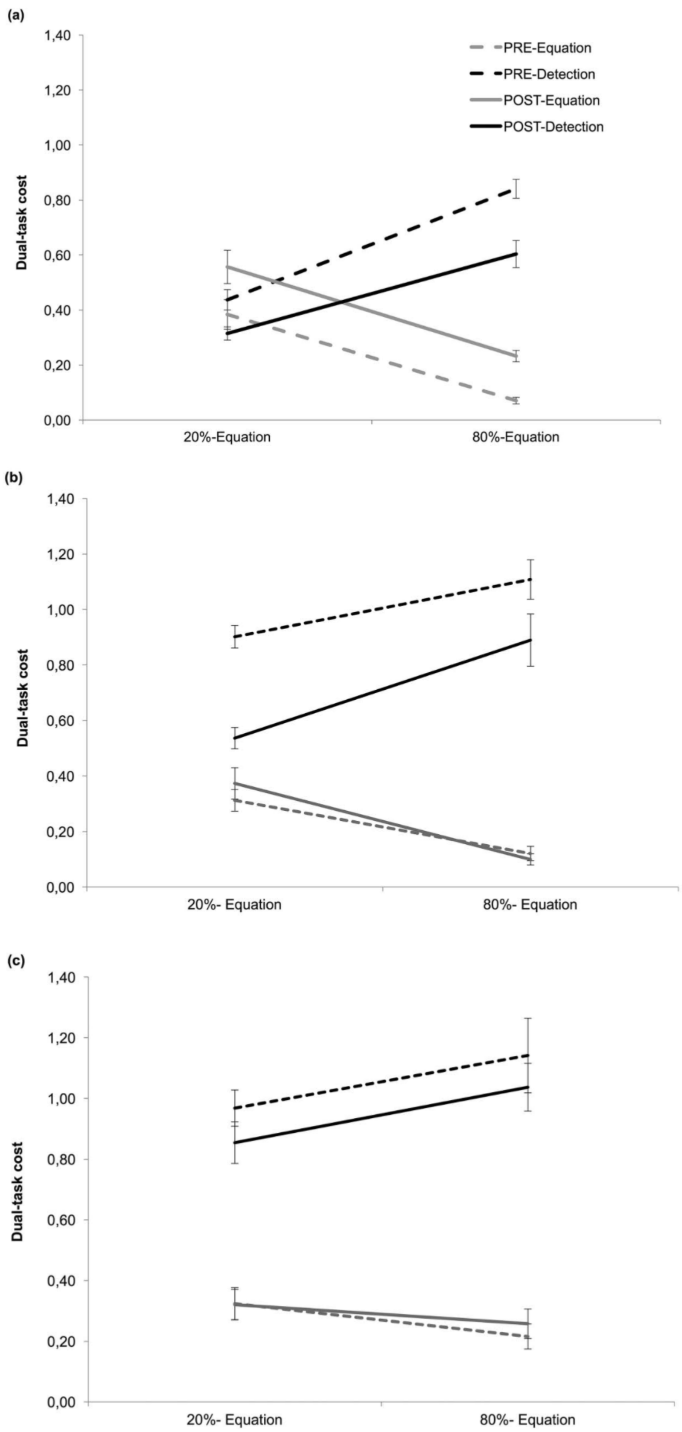


Figure 3. Divided attention cost for (a) young adults (pooled for the two training type) and older adults (b) VARIABLE training and (c) SINGLE-task training, on each task (visual detection; alphanumeric equation) and emphasis instruction condition condition (errors bars represent standard error).

Focused attention

We also examined the effect of training on performance for each task, as some of our participants were trained in a single-task condition. Table 2 shows the pre- and post training performance in focused attention for each training type and age group. To assess the effects of training, mixed ANOVAs were computed separately for each task on AC and RT, using Time (pre and post-training) as a within-subject factor, and Age (old; young) and Training type (SINGLE-task; VARIABLE) as between-subject factors.

Table 2

Performances in single-task alphabetic equation and visual detection (reaction time and accuracy) in pre- and post- sessions for each training type

	Alphanumeric equation				Visual detection task			
	AC		RT		AC		RT	
Age and training type	pre	post	pre	post	pre	post	pre	post
Old								
SINGLE	72.76 (13.33)	84.1* (3.1)	2739.98 (448.67)	2282.99** (388.51)	92.84 (3.24)	94.47 (2.57)	457.85 (32.45)	442.53** (40.15)
DIVIDED	81.24 (9.35)	81.72 (18.94)	2548.72 (298.33)	2110.52** (413.27)	94.68 (2.36)	95.07 (2.24)	445.07 (27.29)	440.83** (37.88)
Young								
SINGLE	79.97 (11.22)	93.70* (3.17)	2152.33 (352.78)	1613.46** (239.41)	95.23 (2.11)	94.30 (1.81)	412.09 (26.83)	402.97** (30.98)
DIVIDED	84.29 (8.18)	90.31 (6.23)	2244.33 (401.82)	1789.97** (409.58)	95.65 (2.29)	94.59 (1.87)	412.39 (40.44)	409.58** (33.21)

Note. Means scores are presented with standard deviations in parentheses. AC = Accuracy; RT = reaction time. * Time x Training type interaction, $p < .05$ ** main effect of Time, $p < .001$ & $p < .05$, respectively.

For the alphanumeric equation task, the ANOVA on AC indicated a Time x Training type interaction, $F(1,53) = 6.61$, $p < .05$ ($\eta 2 = 0.11$), as only participants in SINGLE-task condition improved their accuracy following training ($p < 0.001$, $p = 0.19$, for SINGLE-task and VARIABLE, respectively). A main effect of Age was also found, $F(1, 53) = 9.23$, $p < .05$, due to higher accuracy in younger adults than in older adults. The ANOVA on RT showed a main effect of Time, $F(1, 53) = 141.56$, $p < .001$ ($\eta 2 = 0.73$), due to faster RT following training. A main effect of Age was also found, $F(1, 53) = 27.70$, $p < .001$ ($\eta 2 = 0.34$), as younger adults were faster than older ones. The main Training type effect and the interactions involving that factor did not reach significance for RT ($F < 1$, in all cases).

On visual detection AC, there was an Age x Time interaction, $F(1, 53) = 28.24$, $p < .05$ ($\eta 2 = 0.11$), as younger adults were more accurate than older adults prior to training ($p < .05$), but not following training ($F < 1$). The RT analysis revealed a main Time effect, $F(1, 53)= 4.29$, $p < .05$ ($\eta 2 = 0.10$), indicating that the task was completed more rapidly following training and a main effect of Age, $F(1, 53) = 20.49$, $p < .001$ ($\eta 2 = 0.30$), indicating that younger adults responded faster than older ones. There was neither a main Training type, nor an interaction involving that factor ($F < 1$, in all cases).

Transfer measures

Virtual car ride – Divided attention

The dependent variable of interest for the *Virtual car ride* was the dual-task cost calculated with the following equation: (AC divided – AC focused) / AC focused). Costs were analysed with a mixed ANOVA using Time (pre- and post-training) and Task (road sign detection, Alpha span) as within-subject factors, and Training type (SINGLE-task; VARIABLE) and Age (young; old) as between-subject factors. The Time x Task x Training type x Age interaction just reached significance ($p = .05$). Since we had specific predictions regarding the effect of the training type on transfer, separate Task x Time x Training ANOVAs were computed for each age group.

In younger adults, none of the effects or interactions reached significance including the Task x Time x Training interaction ($F < 1$) (see Figure 4). Inspection of Figure 4 suggests that younger adults reduced their dual-task cost from pre- to post-training on the Alpha span task with both training types. However, the Time x Task interaction just missed significance ($p = .07$), as did the time effect for Alpha span ($p = .07$). No time effect was found on the road sign detection task ($F < 1$). Thus, younger adults did not reduce their dual-task cost in the *Virtual car ride* following training, irrespective of training condition.

Figure 4.

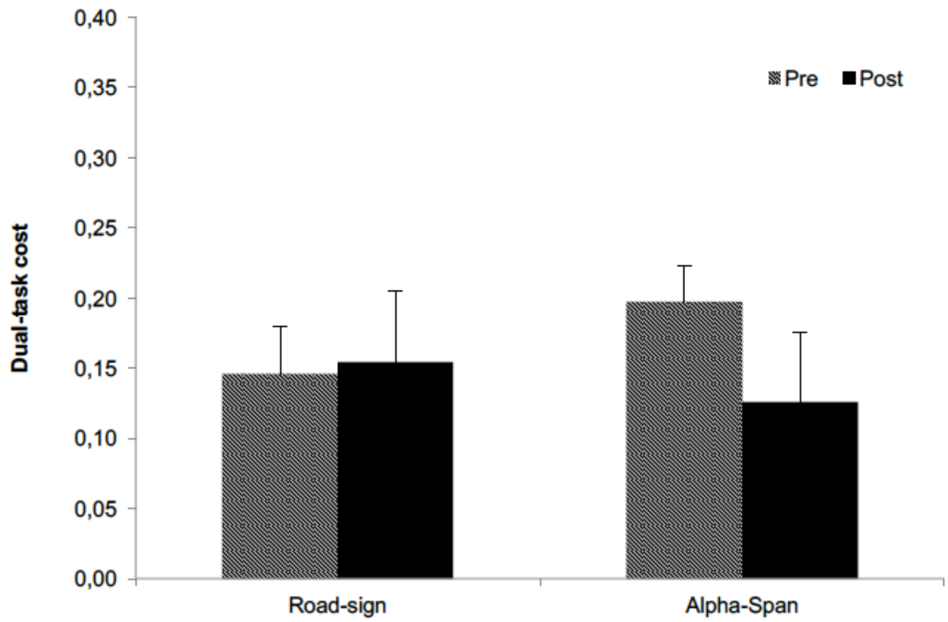


Figure 4. Divided attention cost for young adults (pooled for the two training types) on each task performed in VR (road signs; Alpha-span) at PRE- and POST-training (error bars represent standard error).

For older adults, a significant Task x Time x Training type interaction was found, $F(1, 26) = 3.94$, $p < .05$, ($\eta 2 = 0.15$). Inspection of Figures 5a and 5b indicates that this is due to the fact that VARIABLE priority training improved dual-task cost on both transfer tasks, whereas SINGLE-task training improved only dual-task cost for the Alpha span task. This was confirmed by the decomposition of the interaction. In the VARIABLE training group, we found a main Time effect, $F(1, 26) = 6.50$, $p = .05$, ($\eta 2 = 0.20$), indicating a dual-task cost reduction from pre- ($M = 0.24$) to post-training ($M = 0.13$) irrespective of the task. A main Task effect was also found, which was due to the fact that the dual-task cost was generally larger for the road sign detection than for the Alpha span task, $F(1, 12) = 5.79$, $p < .05$ ($\eta 2 = 0.33$). None of the other effects or interactions reached significance. In the SINGLE-task training group, no Time effect was found ($F < 1$), but the Time x Task interaction was significant, $F(1, 13) = 11.59$, $p < .05$ ($\eta 2 = 0.47$) as participants reduced their dual-task cost following training but only on the Alpha span task (M = 0.25 and M = 0.13 in pre- and post-training respectively; $p < .05$).

Figure 5.

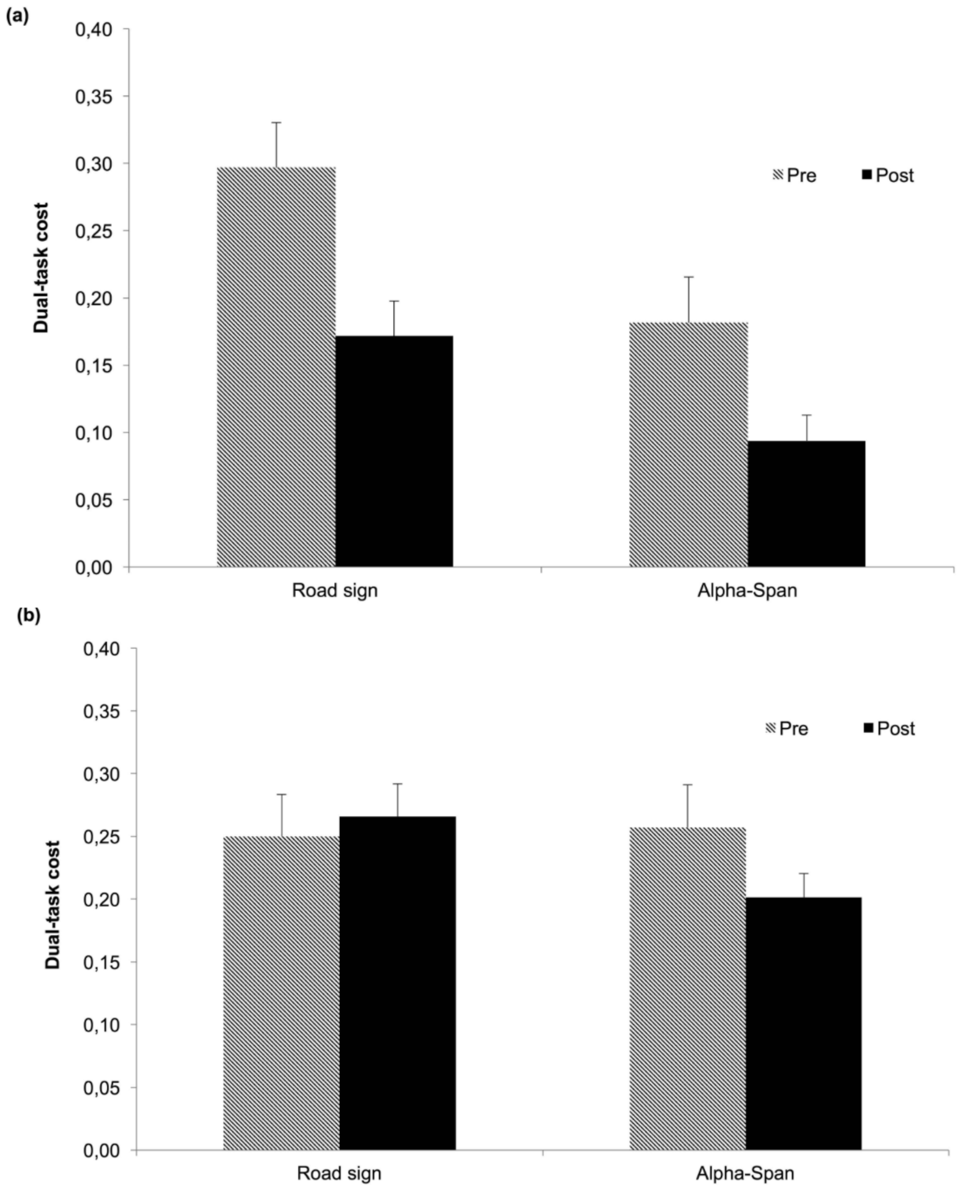


Figure 5. Dual-task cost for older adults in (a) VARIABLE training and (b) SINGLE-task training on each tasks performed in VR (road-signs; Alpha-span) at PRE- and POST-training (error bars represent standard error).

Virtual car ride – Focused attention

To assess transfer in the focused attention condition, mixed ANOVAs were computed separately for each task on AC, using Time (pre- and post-training) as a within-subject factor and Age (Old, Young) and Training type (SINGLE-task, VARIABLE) as between-subject factors. For the Alpha span task, the ANOVA on AC indicated a Time x Age interaction, $F(1,53) = 5.05$, $p < .05$ ($\eta2 = 0.09$), as only younger adults improved their accuracy following training ($p < .05$, $p = 0.69$, for young and older adults, respectively). On the road sign detection task there was a main Time effect, $F(1, 53)= 7.14$, $p < .05$ ($\eta2 = 0.12$), as all participants improved their performance, and a main effect of Age, $F(1, 53)= 52.46$, $p < .001$ ($\eta2 = 0.50$), as younger adults were more accurate than their older counterparts. None of the other effects reached significance.

Cognitive failure questionaire (CFQ)

The Time (pre- and post-training) x Training type (SINGLE-task; VARIABLE) x Age (young; old) ANOVA on the total score of the CFQ revealed that none of the main effects or interactions reached significance ($F < 1$ in all cases).

Correlations

To further assess whether improvement in transfer tasks was due to the favourable effects from the training, we computed correlations between change scores on the *Virtual car ride* dual-task scores and CFQ questionnaire (pre- minus post-training scores) and change scores on three proximal measures: dual-task cost change score (pre- minus post-dual-task cost for the visual detection task in the 20% Equation condition), alphanumeric equation change score (pre- minus post-AC for the alphanumeric equation task performed in focused attention) and visual detection change score (pre- minus post-RT for visual detection performed in focused attention) (see Table 3 a and 4). We chose those variables, as they were the ones for which improvement was found in both age groups. Correlations were computed separately for the two training types and age groups. We also computed correlations between change scores on the CFQ questionnaire and *Virtual car ride* dual-task cost.

Table 3

Correlation Between Change Scores on Proximal Measures and Post-Training Improvement on the VR Tasks in Dual-Task Cost for Each Training Type and Age

	Correlation value					
	Old			Young		
Training type	Road Sign	Alpha Span	CFQ	Road Sign	Alpha Span	CFQ
SINGLE training	0.29	0.94	0.11	0.03	-0.20	0.09
DIVIDED training	0.58**	0.10	0.25	-0.30	-0.15	0.18

Note. CFQ = Cognitive Failures Questionnaire. **Significant at $p < .001$.

For older adults, a strong significant correlation was found for the participants in VARIABLE training between change scores on VR road sign dual-task cost and proximal measure dual-task cost, $r = 0.58$, $p < .001$. This positive correlation indicates that larger dual-task cost improvement on the proximal measures was related to larger dual-task cost improvement on the VR road signs task. There were no other significant correlations (see Table 3). In particular, no correlation was found in the older adults randomized to SINGLE training between the change scores on the alphanumeric equation task or the visual detection task in focused attention and prepost improvement on the VR Alpha span task ($r = 0.16$, $p = .24$) or the CFQ score (see Table 4).

For younger adults in the SINGLE-task training, there was a negative correlation between change scores on the alphanumeric equation task in focused attention and the VR dual-task change cost for Alpha span task ($r = -0.32$, $p = .04$). This negative correlation indicates that a larger improvement on the alphanumeric task after training is related to a larger improvement on the dual-task VR Alpha span task. We also found a positive correlation between change scores in the visual detection task and change scores on the VR dual-task Alpha span task ($r = 0.43$, $p = .02$), indicating that a larger improvement on RT on the visual detection task was related to a larger improvement on the VR dual-task Alpha span task. No correlations were found for the VARIABLE priority training.

Table 4

Correlation Between Change Scores on Proximal Measures and Post-Training Improvement on the VR Tasks in Focused Attention for Each Training Type and Age

		Correlation value					
		Old			Young		
Training type	Proximal Measure	Road Sign	Alpha Span	CFQ	Road Sign	Alpha Span	CFQ
SINGLE training	Alphanumeric equation-AC	-0.12	0.16	0.26	-0.07	-0.32*	0.05
	Visual detection-RT	-0.31	0.02	0.42	0.11	0.43*	-0.32
DIVIDED training	Alphanumeric equation-AC	0.26	0.11	0.15	0.23	0.12	-0.12
	Visual detection-RT	-0.19	-0.23	0.46	-0.44	-0.42	-0.03

Note. CFQ = Cognitive Failures Questionnaire. **Significant at $p < .001$.

DISCUSSION

Younger and older adults received one of two versions of a computerized attentional training program (variable priority; single-task) to examine the effect of age and training type on proximal training effects. We also used an immersive dual-task scenario in VR to measure transfer of training in a real life related context. When measuring the effect on proximal measures, we found that the attentional control abilities of older adults benefited more from training which involved divided attention with allocation variation (variable) than from a training which involved repeated practice of the individual tasks (single-task). We also found evidence of a better transfer on the VR dual-task for older adults trained in the variable priority than for those trained in single-task. Younger adults benefited equally from the two training types when measured with proximal measures of divided attention, but it did not improve their overall dual-task cost and did not improve their attentional control ability. A parallel effect was found in the transfer task, as the two training types only improved Alpha span dual-task cost in younger adults. All participants in the single-task training condition improved their ability to carry out the tasks in the condition of focused attention. Finally, no transfer effects were found on the self-reported measure for either training type or age.

Pattern of Attentional Control Abilities in Younger and Older Adults at Baseline

Using attentional control training in older adults makes sense, as they experience increasing difficulties on these tasks as they age. Our results, which compare older with younger adults at baseline, confirm that older adults are impaired in their ability to flexibly vary attentional allocation when compared to younger adults. At baseline, younger adults were better able to modify allocation priority as a function of task instructions, reducing their dual-task cost properly on the task to be prioritized. In contrast, older adults prioritized the alphanumeric equation over the detection task regardless of emphasis instructions and their dual-task cost did not vary as a function of the task that was to be prioritized. This finding is consistent with substantial data suggesting that older adults are at a disadvantage when required to redeploy attention rapidly and strategically among several tasks performed concurrently (Bier et al., 2014; Hawkins, Kramer, & Capaldi, 1992; Kramer et al., 1995; McDowd & Oseas-Kreger, 1991; McDowd & Shaw, 2000; Salthouse, Rogan, & Prill, 1984). One interesting feature of the paradigm used here is that the alphanumeric equation task is particularly salient and attracts more attention than the detection task prior to training. As a result, participants generally show a lower dual-task cost on the alphanumeric equation task than on visual detection, regardless of the emphasis instruction. This feature poses a particular challenge when participants are asked to emphasize the visual detection task (20% equation). It also makes the paradigm particularly sensitive to attentional control deficit (Bier et al., 2014). Interestingly, while the same pattern (higher global dual-task cost on the visual detection task) was also found in younger adults as in older ones, it did not compromise the younger adults' ability to vary their attentional allocation according to task instructions.

Different Computerized Attentional Training Types Resulted in Specific Training Effects

Given the attentional control impairment found in older adults, attentional training has the potential to provide significant benefits. Here, variable-priority training improved older adults' ability to modify allocation priority as a function of task instructions. Following training, they considerably lowered their dual-task cost on the visual detection task when the instructions required that this task be emphasized, and they showed the opposite effect when the alphanumeric equation needed to be emphasized. In contrast, single-task training did not improve older adults' dual-task cost and their ability to modify attentional allocation. Notably, single-task training was not entirely ineffective. Older adults who received this training improved their accuracy and speed to complete the alphanumeric equation task when performed in focused attention. This confirms that cognitive training programs are specific: They improve the cognitive abilities that they target and yield *content transfer*, that is, transfer to untrained abilities. Further- more, it indicates that being better on individual tasks doesn't necessarily mean that you will be better able to combine those tasks and to control your attention among them. Rather, this requires specific dual-task coordination training, as was provided by the variable-priority training condition (Anguera et al., 2013; Bier et al., 2014). Note that the training results found here in older adults are in line with what is reported in a few prior studies (Bier et al., 2014; Gagnon & Belleville, 2012; Kramer et al., 1995; Lee et al., 2012; Voss et al., 2012), showing benefits of a variable-priority training in reducing dual-task cost in healthy older adults (Bier et al., 2014; Kramer et al., 1995; Lussier et al., 2016) and improving the ability to control attention in response to external demands (Bier et al., 2014; Gopher, 2007; Gopher et al., 1989; Zendel et al., 2016).

Contrary to what was found in older adults, the two training types produced similar effects in younger adults. They both reduced the dual-task cost advantage of the more salient task (alphanumeric equation), which resulted in a dual-task cost increase on alphanumeric equation and a dual-task cost decrease on visual detection. Overall, there was no gain on divided attention or on attentional control. Comparing the data from older and younger adults suggests that the former might benefit more from variable priority training than the latter, to improve their dual-tasking and attentional control capacities. Interestingly, Kramer et al. (1995) also observed a larger benefit from variable priority training in older than in younger adults. A possible explanation is that older adults have more difficulties controlling their attention to begin with, which leaves more room for improvement. One could also argue that younger adults did exert better control of their attention following training, as they reduced their initial bias toward the alphanumeric equation. However, they clearly did not do it in a way that addressed the instructions, which might therefore indicate less compliance. Be this as it may, the fact that the magnitude of the training effect is similar if not larger in older adults compared with younger adults supports the notion that cognitive plasticity for attentional control is preserved in late adulthood and that older adults were provided with the appropriate training. These findings are of major importance since they show that training effects can differ depending on the population to which they are provided.

Impact of Interindividual Differences on Training Effects

The findings reported here are based on group effects. It is possible that interindividual differences determine differences in training efficacy. For instance, a few studies showed that individuals that start with a lower level of performance experience greater training gains than those with a higher level (Jaeggi, Buschkuehl, Jonides, & Shah, 2011; Zinke, Zeintl, Eschen, Herzog, & Kliegel, 2012, 2014). It is therefore possible that persons with lower baseline abilities, older age or lower education, would respond better to the type of training used here. This interpretation is supported by the interactive model, which suggests that training-induced changes might depend on an interaction between training modalities (i.e., format, target, training sequence) and the participant's individual characteristics (Belleville et al., 2014). Thus, one important question is to identify who will benefit most from a cognitive intervention and whether factors such as baseline cognitive strengths and weaknesses, cerebral characteristics or personality differences, modulate a participant's response to cognitive training (Erickson et al., 2010; Jaeggi, Buschkuehl, Shah, & Jonides, 2014; Katz, Jones, Shah, Buschkuehl, & Jaeggi, 2016).

It is also important to address whether these interventions could be used with clinical populations. Importantly, Gagnon and Belleville (2012) found improvements from variable priority training on attentional control capacities and transfer to other executive tasks in amnestic MCI individuals who showed executive deficits at baseline. This result suggests that mildly impaired populations can benefit from this type of training and that the presence of executive deficits does not preclude a positive effect to occur. This could have tremendous implications, as the presence of executive impairment was associated with increased difficulties in daily life and was suggested to exacerbate functional impairment. Thus, providing training that targets these difficulties might have a positive impact on functional autonomy. Targeting attentional control abilities could also benefit other clinical populations characterized by attentional or executive deficits, such as younger or older adults with a traumatic brain injury (TBI) or poststroke populations. Cognitive interventions have been widely used in these populations, but results suggest poor generalization of training effect to broader outcomes (Barker-Collo et al., 2009; Fetta, Starkweather, & Gill, 2017; Palmese & Raskin, 2000; Park, 1999; Sohlberg, McLaughlin, Pavese, Heidrich, & Posner, 2000). Future research could assess whether the benefits of variable priority training can be found in these clinical populations and whether it favors transfer effects.

Transfer of Training is Modulated by Training Format and Age

One major goal was to contribute to our knowledge on training transfer and particularly, to determine whether the benefits of training could generalize to a novel complex VR scenario, the *Virtual car ride* in contrast to a self-reported questionnaire and whether training type (single-task vs. variable-priority) and age had an impact on the magnitude of the transfer.

As expected, we found larger generalization of training gains on the dual-task cost experienced in the *Virtual car ride* for the older adults trained in variable-priority compared to the ones trained in single-task training. Indeed, participants trained in the variable-priority training showed a significant dual-task cost reduction from pre- to post-training on the two tasks performed in VR (road sign detection; Alpha span task), whereas this was not found in older adults enrolled in the single-task training. Furthermore, training gain on the VR dual-task cost was correlated with training gain on the proximal dual-task outcome, which confirms that it reflects actual transfer, whereas this was not the case for single-task training. Note that performance on the Alpha span task was improved in the single-task training. However, there is reason to believe that this is due to practice effects and to the fact that this task involves alphabet search, which was highly practiced in the alphanumeric equation. First, participants trained in the single-task condition improved their performance on alphanumeric equation in focused attention, which indicates that practice improved their ability for alphabetical search. Second, correlations were found in younger adults between the improvement on alphanumeric equation in focused attention and the VR Alpha-span dual-task cost reduction. Third, we did not find any correlation between improvements on proximal dual-task cost training reduction and VR Alpha-span dual-task cost reduction in the single-task training group. Fourth, younger adults, who did not improve their attentional control abilities, also showed a small nonsignificant improvement on the VR Alpha span task. These suggest that the improvement on Alpha span may be due to changes in a process different from the one that underlies attentional control, possibly better alphabetic search ability and better knowledge of the alphabetical order.

Overall, we found more evidence of *context transfer* than *content transfer*. *Content transfer* refers to transfer on cognitive abilities or tasks that are not trained (experimental or cognitive tasks) whereas *context transfer* refers to transfer of a learned skill or strategy in a new context (at home or in a more complex environment). Variable-priority training led to transfer effects on dual-tasking abilities measured in VR. Thus, it transferred to an attentional control scenario performed in a virtually different context, a virtual car ride, but which involves the same cognitive processes as those trained. These results are in line with Gopher et al. (1994) and Hart and Battiste (1992) who found that benefits from variable priority training in younger adults generalized to a new complex and high demanding real-life related situations (flight performance). It is of note that contrary to these studies, transfer on the VR dual-task was not found in younger adults but only in healthy older adults. However, this is consistent with the data on proximal measures, as this is the group of older adults that showed improvement on proximal measures of attentional control. One could argue that single-task training also produced some *context transfer* since performance improved in the focused attention condition of the VR road sign detection task. Single-task training shows little evidence for *content transfer*, in that it does not lead to better attentional control abilities, as proximal measures are concerned.

These findings are highly relevant to the field of cognitive aging, as evidence that attentional training could lead to *context transfer* in healthy older adults was lacking. Some studies reported *content transfer* in healthy older adults following variable-priority training (Kramer et al., 1995; Kramer, Hahn, & Gopher, 1999; Lussier et al., 2016), where improvement was transferred to a task that was modified with respect to modality, response, or material. However, the innovative feature of the present study was to use a transfer task that is more related to a real life setting and might therefore be used as a proxy for *context transfer*. Furthermore, this study examined the effect of age on transfer effects. Results of the present study suggest nonequivalent age generalizable gains as the magnitude of transfer was larger for older adults compared with their younger counterparts. This is quite an interesting finding, especially in light of the often reported observation of reduced training benefits for older adults (Brehmer, Westerberg & Bäckman, 2012; Zinke et al., 2014). These results bring further support to the notion that cognitive plasticity is preserved in advanced age and that transfer to more complex tasks is possible in later adulthood.

Measuring Transfer of Training With Virtual Reality

One of the major contributions of the present study was to use transfer tasks that reflect real life situation, as most studies carried out with older adults measured transfer with self-reported questionnaires or tasks that lack in ecological validity. To our knowledge, this is the first study to use VR as a tool to evaluate transfer of training in an older population. We were able to measure transfer effects in the *Virtual car ride*, an immersive dual-task scenario designed to mimic the complexity of a real life situation. We also showed that these effects were not captured by the self-reported questionnaire, as no difference was found on the total score from pre- to post-training.

The present results are encouraging, as evidence of transfer to novel dual-task situations in more complex environments is scarce, particularly in older adults. Furthermore, VR may be an alternative tool to appraise cognitive performance, as traditional tasks are shown to have a limited predictive value for everyday performance (Chaytor & Schmitter-Edgecombe, 2003). In addition, transfer effects obtained on experimental tasks that only differ in terms of stimuli or response modality may be more difficult to generalize to a context from daily life. VR tasks were also shown to be more motivating for participants compared to traditional laboratory tasks, because of their engaging aspects (Corriveau-Lecavalier et al., 2017). Motivation is thus a crucial factor that could not only impact cognitive performance (Leeb et al., 2007), but also limit withdrawals from training research programs.

Limitations

It is important to recognize some of the limitations of this study. First, the number of participants per training group was small. Although our sample size proved to be sufficient to find a robust training effect, it might have been possible to detect more subtle differences with larger groups. Second, the level of difficulty of the tasks on proximal outcome and transfer measures was not adjusted, which might have reduced our ability to observe training gains and transfer effects in younger adults. Third, we did not include a fixed priority divided attention training condition. Thus, it is unclear whether such a training condition would have improved dual-task performance in the *Virtual car ride*. Even if the *Virtual car ride* was constructed to be more representative of a real-life context and hence more ecologically valid than typical transfer measures, it is still an experimental task, as it is performed in a laboratory and in a controlled and standardized environment. Finally, cybersickness is a concern when using VR and it could limit its broad application, particularly with older adults, as they might be vulnerable to theses symptoms. Of note, our participants did not experience many of these symptoms. This might have been due to the short duration of the task and to the fact that they were seated during the tasks and few head movements were required, which could have helped reduce symptoms.

Conclusion and Future Research

In conclusion, we showed that divided attention variable-priority training improves older adults' attentional control capacities and dual-task performance and that the benefits are specific, in that the repeated practice of an individual task (single-task) improves neither dual-tasking nor attentional control. Older adults were impaired relative to younger ones prior to training and hence, the positive effect of variable-priority training was present only in the former. This indicates that attention remains plastic in old age and that programs meant to improve attentional control might be more beneficial to older and/or more challenged individuals. Importantly, the training effect found in this study transferred to a virtual reality task that reflects the complexity of the processes involved in attentional tasks of everyday living, which suggests that training can produce *context transfer* and that transfer may remain possible throughout the life span. Little is known about the extent and limits of transfer effects following cognitive training and measuring transfer is challenging, as we have very few tools that can provide objective measures of performance in complex activities of daily life. The present study innovates by measuring transfer effects using an immersive dual-task paradigm in VR and demonstrates its potential as a sensitive measure of *context transfer* for training in older adults. With the growing accessibility of VR devices in terms of cost and portability (wireless and smaller headset), the technique may represent an interesting avenue as a transfer measure, but also as a tool for training (Shuchat, Ouellet, Moffat, & Belleville, 2012). Finally, more attention should be given to training components that enhance transfer.

REFERENCES

Allain, P., Foloppe, D. A., Besnard, J., Yamaguchi, T., Etcharry-Bouyx, F., Le Gall, D., . . . Richard, P. (2014). Detecting everyday action deficits in Alzheimer's disease using a nonimmersive virtual reality kitchen. *Journal of the International Neuropsychological Society, 20,* 468–477. doi:10.1017/S1355617714000344

Anguera, J. A., Boccanfuso, J., Rintoul, J. L., Al-Hashimi, O., Faraji, F., Janowich, J., . . . Gazzaley, A. (2013). Video game training enhances cognitive control in older adults. *Nature, 501,* 97–101. doi:10.1038/nature12486

Ball, K., Berch, D. B., Helmers, K. F., Jobe, J. B., Leveck, M. D., Marsiske, M., . . . Willis, S. L. (2002). Effects of cognitive training interventions with older adults: A randomized controlled trial. *Journal of the American Medical Association, 288,* 2271–2281. doi:10.1001/jama.288.18.2271

Barker-Collo, S. L., Feigin, V. L., Lawes, C. M., Parag, V., Senior, H., & Rodgers, A. (2009). Reducing attention deficits after stroke using attention process training: A randomized controlled trial. *Stroke, 40,* 3293– 3298. doi:10.1161/STROKEAHA.109.558239

Barnett, S. M., & Ceci, S. J. (2002). When and where do we apply what we learn? A taxonomy for far transfer. *Psychological Bulletin, 128,* 612– 637. doi:10.1037/0033-2909.128.4.612

Belleville, S., Mellah, S., de Boysson, C., Demonet, J.-F., & Bier, B. (2014). The pattern and loci of training-induced brain changes in healthy older adults are predicted by the nature of the intervention. *PLoS ONE, 9,* e102710. doi:10.1371/journal.pone.0102710

Belleville, S., Rouleau, N., & Caza, N. (1998). Effect of normal aging on the manipulation of information in working memory. *Memory & Cognition, 26,* 572–583. doi:10.3758/BF03201163

Bherer, L., Kramer, A. F., Peterson, M. S., Colcombe, S., Erickson, K., & Becic, E. (2005). Training effects on dual-task performance: Are there age-related differences in plasticity of attentional control? *Psychology and Aging, 20,* 695–709. doi:10.1037/0882-7974.20.4.695

Bherer, L., Kramer, A. F., Peterson, M. S., Colcombe, S., Erickson, K., & Becic, E. (2008). Transfer effects in task-set cost and dual-task cost after dual-task training in older and younger adults: Further evidence for cognitive plasticity in attentional control in late adulthood. *Experimental Aging Research, 34,* 188–219. doi:10.1080/03610730802070068

Bier, B., de Boysson, C., & Belleville, S. (2014). Identifying training modalities to improve multitasking in older adults. *Age, 36,* 9688. doi:10.1007/s11357-014-9688-2

Boot, W. R., Basak, C., Erickson, K. I., Neider, M., Simons, D. J., Fabiani, M., . . . Kramer, A. F. (2010). Transfer of skill engendered by complex task training under conditions of variable priority. *Acta Psychologica, 135,* 349–357. doi:10.1016/j.actpsy.2010.09.005

Bransford, J. D., Brown, A. L., & Cocking, R. R. (2000). Learning and transfer. *How people learn: Brain, mind, experience, and school*. Washington, DC: National Academies Press.

Braver, T. S., Barch, D. M., Keys, B. A., Carter, C. S., Cohen, J. D., Kaye, J. A., . . . Reed, B. R. (2001). Context processing in older adults: Evidence for a theory relating cognitive control to neurobiology in healthy aging. *Journal of Experimental Psychology: General, 130,* 746 – 763. doi:10.1037/0096-3445.130.4.746

Braver, T. S., & West, R. (2008). Working memory, executive control, and aging. *The Handbook of Aging and Cognition, 3,* 311–372.

Brehmer, Y., Westerberg, H., & Bäckman, L. (2012). Working-memory training in younger and older adults: Training gains, transfer, and maintenance. *Frontiers in Human Neuroscience, 6,* 63.

Broadbent, D. E., Cooper, P. F., FitzGerald, P., & Parkes, K. R. (1982). The cognitive failures questionnaire (CFQ) and its correlates. *British Journal of Clinical Psychology, 21*(Part 1), 1–16. doi:10 .1111/j.2044-8260.1982.tb01421.x

Butterfield, E. C., & Nelson, G. D. (1991). Promoting positive transfer of different types. *Cognition and Instruction, 8,* 69–102. doi:10.1207/s1532690xci0801_3

Chandler, M. J., Parks, A. C., Marsiske, M., Rotblatt, L. J., & Smith, G. E. (2016). Everyday impact of cognitive interventions in mild cognitive impairment: A systematic review and meta-analysis. *Neuropsychology Review, 26,* 225–251. doi:10.1007/s11065-016-9330-4

Chaytor, N., & Schmitter-Edgecombe, M. (2003). The ecological validity of neuropsychological tests: A review of the literature on everyday cognitive skills. *Neuropsychology Review, 13,* 181–197. doi:10.1023/B:NERV.0000009483.91468.fb

Corriveau-Lecavalier, N., Ouellet, E., Boller, B., & Belleville, S. (2017). Use of immersive virtual reality to assess episodic memory: A validation study in older adults. *Neuropsychological Rehabilitation*.

Cushman, L. A., Stein, K., & Duffy, C. J. (2008). Detecting navigational deficits in cognitive aging and Alzheimer disease using virtual reality. *Neurology, 71,* 888–895. doi:10.1212/01.wnl.0000326262 .67613.fe

Dahlin, E., Neely, A. S., Larsson, A., Bäckman, L., & Nyberg, L. (2008). Transfer of learning after updating training mediated by the striatum. *Science, 320,* 1510–1512. doi:10.1126/science.1155466

Derwinger, A., Neely, A. S., Persson, M., Hill, R. D., & Bäckman, L. (2003). Remembering numbers in old age: Mnemonic training versus self-generated strategy training. *Aging, Neuropsychology and Cognition, 10,* 202–214. doi:10.1076/anec.10.3.202.16452

Erickson, K. I., Boot, W. R., Basak, C., Neider, M. B., Prakash, R. S., Voss, M. W., . . . Kramer, A. F. (2010). Striatal volume predicts level of video game skill acquisition. *Cerebral Cortex, 20,* 2522–2530. doi:10.1093/cercor/bhp293

Fetta, J., Starkweather, A., & Gill, J. M. (2017). Computer-based cognitive rehabilitation interventions for traumatic brain injury: A critical review of the literature. *Journal of Neuroscience Nursing, 49,* 235–240. doi:10.1097/JNN.0000000000000298

Gagnon, L. G., & Belleville, S. (2012). Training of attentional control in mild cognitive impairment with executive deficits: Results from a double-blind randomised controlled study. *Neuropsychological Rehabilitation, 22,* 809–835. doi:10.1080/09602011.2012.691044

Gopher, D. (2007). Emphasis change as a training protocol for high-demand tasks. In A. F. Kramer, D. A. Wiegmann, & A. Kirlik (Eds.), *Attention: From theory to practice* (pp. 209–224). New York, NY: University Press.

Gopher, D., Weil, M., & Bareket, T. (1994). Transfer of skill from a computer game trainer to flight. *Human Factors, 36,* 387–405. doi:10.1177/001872089403600301

Gopher, D., Weil, M., & Siegel, D. (1989). Practice under changing priorities: An approach to the training of complex skills. *Acta Psychologica, 71,* 147–177. doi:10.1016/0001-6918(89)90007-3

Hart, S. G., & Battiste, V. (1992). Field test of video game trainer. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 36,* 1291– 1295. doi:10.1518/107118192786749450

Hawkins, H. L., Kramer, A. F., & Capaldi, D. (1992). Aging, exercise, and attention. *Psychology and Aging, 7,* 643– 653. doi:10.1037/ 0882-7974.7.4.643

Jaeggi, S. M., Buschkuehl, M., Jonides, J., & Shah, P. (2011). Short- and long-term benefits of cognitive training. *Proceedings of the National Academy of Sciences of the United States of America, 108,* 10081– 10086. doi:10.1073/pnas.1103228108

Jaeggi, S. M., Buschkuehl, M., Shah, P., & Jonides, J. (2014). The role of individual differences in cognitive training and transfer. *Memory & Cognition, 42,* 464–480.

Karbach, J., & Schubert, T. (2013). Training-induced cognitive and neural plasticity. *Frontiers in Human Neuroscience*, *7*(article 48), 1–2. doi:10.3389/fnhum.2013.00048

Katz, B., Jones, M. R., Shah, P., Buschkuehl, M., & Jaeggi, S. M. (2016). Individual differences and motivational effects. In T. Strobach & J. Karbach (Eds.), *Cognitive Training* (pp. 157–166). Cham, Switzerland: Springer International Publishing.

Kramer, A. F., Hahn, S., & Gopher, D. (1999). Task coordination and aging: Explorations of executive control processes in the task switching paradigm. *Acta Psychologica, 101*(2–3), 339–378. doi:10.1016/S0001-6918(99)00011-6

Kramer, A. F., Larish, J. F., & Strayer, D. L. (1995). Training for attentional control in dual task settings: A comparison of young and old adults. *Journal of Experimental Psychology: Applied, 1,* 50–76. doi:10.1037/1076-898X.1.1.50

Kühn, S., & Lindenberger, U. (2016). Research on human plasticity in adulthood: A lifespan agenda. In K. W. Schaie & S. L. Willis (Eds.), *Handbook of the psychology of aging* (8th ed., pp. 105–123). Hoboken, NJ: John Wiley & Sons, Inc.

Lee, H., Voss, M. W., Prakash, R. S., Boot, W. R., Vo, L. T. K., Basak, C., . . . Kramer, A. F. (2012). Videogame training strategy-induced change in brain function during a complex visuomotor task. *Behavioural Brain Research, 232,* 348–357. doi:10.1016/j.bbr.2012.03.043

Leeb, R., Lee, F., Keinrath, C., Scherer, R., Bischof, H., & Pfurtscheller, G. (2007). Brain-computer communication: Motivation, aim, and impact of exploring a virtual apartment. *IEEE Transactions on Neural Systems and Rehabilitation Engineering, 15,* 473–482. doi:10.1109/ TNSRE.2007.906956

Lobato, J. (2006). Alternative perspectives on the transfer of learning: History, issues, and challenges for future research. *Journal of the Learning Sciences, 15,* 431–449. doi:10.1207/s15327809jls1504_1

Lövdén, M., Bäckman, L., Lindenberger, U., Schaefer, S., & Schmiedek, F. (2010). A theoretical framework for the study of adult cognitive plasticity. *Psychological Bulletin, 136,* 659–676. doi:1037/a0020080

Lussier, M., Bugaiska, A., & Bherer, L. (2016). Specific transfer effects following variable priority dual-task training in older adults. *Restorative Neurology and Neuroscience, 35,* 237–250. doi:10.3233/RNN-150581

Lussier, M., Gagnon, C., & Bherer, L. (2012). An investigation of response and stimulus modality transfer effects after dual-task training in younger and older. *Frontiers in Human Neuroscience, 6,* 129. doi:10.3389/fnhum.2012.00129

Lustig, C., Shah, P., Seidler, R., & Reuter-Lorenz, P. A. (2009). Aging, training, and the brain: A review and future directions. *Neuropsychology Review, 19,* 504–522. doi:10.1007/s11065-009-9119-9

McDowd, J. M., & Oseas-Kreger, D. M. (1991). Aging, inhibitory processes, and negative priming. *Journal of Gerontology, 46,* 340–345. doi:10.1093/geronj/46.6.P340

McDowd, J. M., & Shaw, R. J. (2000). Attention and aging: A functional perspective. In F. I. M. Craik & T. A. Salthouse (Eds.), *The handbook of aging and cognition* (pp. 221–292). Mahwah, NJ: Lawrence Erlbaum Associates Publishers.

Melby-Lervåg, M., & Hulme, C. (2013). Is working memory training effective? A meta-analytic review. *Developmental Psychology, 49,* 270 – 291. doi:10.1037/a0028228

Milham, M. P., Erickson, K. I., Banich, M. T., Kramer, A. F., Webb, A., Wszalek, T., & Cohen, N. J. (2002). Attentional control in the aging brain: Insights from an fMRI study of the Stroop task. *Brain and Cognition, 49,* 277–296. doi:10.1006/brcg.2001.1501

Nasreddine, Z. S., Phillips, N. A., Bédirian, V., Charbonneau, S., Whitehead, V., Collin, I., . . . Chertkow, H. (2005). The Montreal Cognitive Assessment, MoCA: A brief screening tool for mild cognitive impairment. *Journal of the American Geriatrics Society, 53,* 695–699. doi:10.1111/j.1532-5415.2005.53221.x

Neely, A. S., & Backman, L. (1993). Maintenance of gains following multifactorial and unifactorial memory training in late adulthood. *Educational Gerontology: An International Quarterly, 19,* 105–117. doi:10.1080/0360127930190202

Noack, H., Lövdén, M., Schmiedek, F., & Lindenberger, U. (2009). Cognitive plasticity in adulthood and old age: Gauging the generality of cognitive intervention effects. *Restorative Neurology and Neuroscience, 27,* 435–453. doi:10.3233/RNN-2009-0496

Owen, A. M., Hampshire, A., Grahn, J. A., Stenton, R., Dajani, S., Burns, A. S., . . . Ballard, C. G. (2010). Putting brain training to the test. *Nature, 465,* 775–778. doi:10.1038/nature09042

Palmese, C. A., & Raskin, S. A. (2000). The rehabilitation of attention in individuals with mild traumatic brain injury, using the APT-II programme. *Brain Injury, 14,* 535–548.

Park, N. W. (1999). Evaluation of the attention process training program. *Neuropsychological Rehabilitation, 9,* 135–154. doi:10.1080/713755595

Perkins, D. N., & Salomon, G. (1988). Teaching for transfer. *Educational Leadership, 46,* 22–32.

Perkins, D. N., & Salomon, G. (1992). Transfer of learning. *International Encyclopedia of Education, 2,* 6452–6457.

Plancher, G., Gyselinck, V., Nicolas, S., & Piolino, P. (2010). Age effect on components of episodic memory and feature binding: A virtual reality study. *Neuropsychology, 24,* 379–390. doi:10.1037/ a0018680

Rebok, G. W., Ball, K., Guey, L. T., Jones, R. N., Kim, H. Y., King, J. W., . . . Willis, S. L. (2014). Ten-year effects of the advanced cognitive training for independent and vital elderly cognitive training trial on cognition and everyday functioning in older adults. *Journal of the American Geriatrics Society, 62,* 16 –24. doi:10.1111/jgs .12607

Rizzo, A. A., Schultheis, M., Kerns, K. A., & Mateer, C. (2004). Analysis of assets for virtual reality applications in neuropsychology. *Neuropsychological Rehabilitation, 14*(1–2), 207–239. doi:10.1080/ 09602010343000183

Salthouse, T. A., Rogan, J. D., & Prill, K. A. (1984). Division of attention: Age differences on a visually presented memory task. *Memory & Cognition, 12,* 613–620. doi:10.3758/BF03213350

Saposnik, G., Cohen, L. G., Mamdani, M., Pooyania, S., Ploughman, M., Cheung, D., . . . Bayley, M. (2016). Efficacy and safety of non-immersive virtual reality exercising in stroke rehabilitation (EVREST): A randomised, multicentre, single-blind, controlled trial. *Lancet Neurology, 15,* 1019 –1027. doi:10.1016/S1474-4422(16)30121-1

Schuemie, M. J., van der Straaten, P., Krijn, M., & van der Mast, C. A. (2001). Research on presence in virtual reality: A survey. *CyberPsychology & Behavior, 4,* 183–201. doi:10.1089/ 109493101300117884

Schulz, K. F., Altman, D. G., & Moher, D. (2010). CONSORT 2010 Statement: Updated guidelines for reporting parallel group randomised trials. *Trials, 11,* 32.

Shuchat, J., Ouellet, É., Moffat, N., & Belleville, S. (2012). Opportunities for virtual reality in cognitive training with persons with mild cognitive impairment or Alzheimer's disease. *Non-Pharmacological Therapies in Dementia, 3,* 35–54.

Sohlberg, M., McLaughlin, K. A., Pavese, A., Heidrich, A., & Posner, M. I. (2000). Evaluation of attention process training and brain injury education in persons with acquired brain injury. *Journal of Clinical and Experimental Neuropsychology, 22,* 656–676. doi:10.1076/1380-3395(200010)22:5;1-9;FT656

Stuss, D. T., Robertson, I. H., Craik, F. I., Levine, B., Alexander, M. P., Black, S., . . . Winocur, G. (2007). Cognitive rehabilitation in the elderly: A randomized trial to evaluate a new protocol. *Journal of the International Neuropsychological Society, 13,* 120–131. doi:10 .1017/S1355617707070154

Voss, M. W., Prakash, R. S., Erickson, K. I., Boot, W. R., Basak, C., Neider, M. B., . . . Kramer, A. F. (2012). Effects of training strategies implemented in a complex videogame on functional connectivity of attentional networks. *NeuroImage, 59,* 138 – 148. doi:10.1016/j.neuroimage.2011.03.052

Waller, D., Hunt, E., & Knapp, D. (1998). The transfer of spatial knowledge in virtual environment training. *Presence, 7,* 129–143. doi:10.1162/105474698565631

Wechsler, D. (1997). *Wechsler Memory Scale–Third Edition.* San Antonio, TX: The Psychological Corporation.

Wechsler, D. (2008). *Wechsler Adult Intelligence Scale–Fourth Edition*. San Antonio, TX: The Psychological Corporation.

Willis, S. L., Tennstedt, S. L., Marsiske, M., Ball, K., Elias, J., Koepke, K. M., . . . Wright, E. (2006). Long-term effects of cognitive training on everyday functional outcomes in older adults. *Journal of the American Medical Association, 296,* 2805–2814. doi:10.1001/jama .296.23.2805

Witmer, B. G., & Singer, M. J. (1998). Measuring presence in virtual environments: A presence questionnaire. *Presence, 7,* 225–240. doi:10.1162/105474698565686

Zanardo, F., De Beni, R., & Moè, A. (2006). Influence of other-beliefs on self-beliefs and on everyday memory self-report in the elderly. *Aging Clinical and Experimental Research, 18,* 425–432. doi:10 .1007/BF03324839

Zendel, B. R., de Boysson, C., Mellah, S., Démonet, J.-F., & Belleville, S. (2016). The impact of attentional training on event-related potentials in older adults. *Neurobiology of Aging, 47,* 10–22. doi:10.1016/j.neurobiolaging.2016.06.023

Zinke, K., Zeintl, M., Eschen, A., Herzog, C., & Kliegel, M. (2012). Potentials and limits of plasticity induced by working memory training in old-old age. *Gerontology, 58,* 79–87. doi:10.1159/ 000324240

Zinke, K., Zeintl, M., Rose, N. S., Putzmann, J., Pydde, A., & Kliegel, M. (2014). Working memory training and transfer in older adults: Effects of age, baseline performance, and training gains. *Developmental Psychology, 50,* 304–315. doi:10.1037/a0032982